VOLUTION FOR JOHN DOE

Henshaw Ward

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EVOLUTION FOR JOHN DOE

Evolution for John Doe

By

HENSHAW WARD

With Foreword by
LORANDE LOSS WOODRUFF

Illustrated

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INDIANAPOLIS
THE BOBBS-MERRILL COMPANY
PUBLISHERS

19843

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Printed in the United States of America

PRINTED AND BOUND
BY BRAUNWORTH & CO., INC.
BROOKLYN, NEW YORK

FOREWORD

by

LORANDE LOSS WOODRUFF

Professor of Protozoology at Yale University

Mr. Ward has demonstrated in the present volume that it is possible for the layman to put in forceful, popular language a vivid, general view of what is meant by organic evolution. He gives just such a survey as a person unacquainted with biology needs for an introduction to some of the large problems of life—problems so large that they have burst the confines of the biological laboratory to trouble unnecessarily some politicians and theologians.

The reader who has been curious about these questions will, I feel sure, find that his interest in the book grows as he proceeds, and will finish it with the desire to fill out the general picture he has obtained by turning to some of the critical treatises which the author suggests. Mr. Ward opens the door.

ACKNOWLEDGMENTS TO

ALBERT GALLOWAY KELLER, CHESTER RAY LONGWELL AND LORANDE LOSS WOODRUFF.

My dear Keller:

If you would let me tell you in private how I feel about your share in this undertaking, I should not make you uncomfortable by displaying your name in such a public way. But since you will not listen, you must read. When you gave me the benefit of your twenty years of experience in teaching evolution without being a biologist, you showed the way through the maze; by giving criticism at every step you prevented a lot of blunders. I want you to know that I am grateful for making the path and trying to keep me in it.

After you had been so tireless in helping me for two years, you went further. You persuaded Professor Longwell to criticize the chapter on geology and to put me in his debt for some very useful comments. Then you enticed into my service a critic who could remove some technical mistakes, whose imagination was equal to sympathizing with this strange amateur enterprise, and whose kindness made him unsparing. I am sure you want to join me in thanking Professor Woodruff for this aid, of a sort that few biologists could give.

No sensible scientist will find fault with him if he has not removed all the mistakes from this book, nor will readers blame you if my printed words are less racy than your spoken ones. Nor could you transfuse into it the teaching skill with which you enliven the subject in the classroom. You and he have done all that was possible, laboring with such generosity as I have never before seen in my struggle for existence.

Henshaw Ward.

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PART ONE

A Description of Evolution

To the mind of John Doe there is something mystical and awesome about "Evolution," especially if it is printed with a large *E*. The evolution in this book is usually printed with a small *e* and means only the very plain scientific theory that every form of plant or animal that ever lived developed out of a previous form.

John Doe guesses that evolution is true, but he rather wishes it were not. He has a vague fear that the theory is materialistic and tends to weaken religious faith. If he reads the opinions of eminent divines in Part Three, he will find that there is no ground for his fear. Recently a young Presbyterian minister said to me, "All our theology is now based on evolution." He represents the thought of many divinity schools to-day.

John Doe suspects from head-lines in his newspaper that evolution is a debatable theory, that it is being overthrown every six months, and that it may be discarded before long. When he has read section four of Chapter XXIV, he will understand that evolution is here to stay; there is no more chance that the theory will be disproved than there is that men will some time give up their belief that the earth is round; every reputable modern scientist believes in it as a matter of course. It is now an integral part of all general education and culture. To suppose that it may some day be abandoned is to live in intellectual barbarism.

To the common horse-sense of John Doe evolution appears probable. "But," he says, "it is not to be seen at work here and now, and so it looks dubious to me." When he has seen the "billion-year movie" in Chapter XII, he will feel relieved.

Mr. Doe supposes that evolution is extremely difficult, so that he has small chance of ever finding out

about it. For this supposition he is excusable. It is true that most scientific books are highly technical, and that evolution is based on several branches of science at once, and that each is hard to learn about, and that the combination of several in one theory is excessively complicated. Also it is true that, to the best of my knowledge, no simple explanation has ever been put into a volume. For twenty years I have tried to find some book in a popular style that I could place in the hands of young men who were curious to read about evolution, and I have longed to find such a treatment for myself, which would give me in a few hours an outline of the information that is hidden in the forbidding tomes of science. I have examined several volumes that were said to be of this sort, but not one would serve my purpose. Librarians are constantly asked for "something simple about evolution," but they have to shake their heads sadly. Apparently the biologists know so much of the details that they can not write a brief account of the whole theory. Not one of them has begun at the beginning of my ignorance and shown me, step by step, an outline of the whole. I see a lot of chapters about "Somatogenesis" and "Mendelism" and "Neo-Lamarckism," but I am lost in a wilderness of big words, and I haven't any sketch-map.

Probably most intelligent people have tried during the last quarter-century to learn something about a theory that has remodeled all the world's knowledge and profoundly affected its way of thinking. Last year I grew so desperate as to read a number of the standard works on evolution, and I was curious to see whether I could form a digest of the bewildering array of different branches of science to which all the authors have to appeal. I have written it out as if I were telling a friend about the knowledge that is so

new and imperfect in my mind. It seems reckless to publish this. Yet the signs are that no professional scientist is ever going to attempt this job that so sorely needs to be done. Some amateur must try.

Evolution for John Doe is not a proof of anything, because evolution has never been mathematically demonstrated. It is not an argument, because there is no sense in a layman's arguing for or against the entire body of learned men whose business it is to study organic life. It is merely an outline of what this body of scholars conceives to be the explanation of how living forms have developed. It begins at the beginning, with sketches of the facts, and gives descriptions of how scientists look at nature.

If you are not familiar with the history of scientific thought and not too eager to begin to read of evolution, spend a couple of minutes with the next paragraph, which is about the theory that the earth moves. It is an excellent preparation for the chapters that follow.

The normal human brain, unfamiliar with the facts of astronomy, can not conceive that the earth goes around the sun. A thousand generations of the most observant minds that earth could breed never suspected such an idea. Men learned to build great cities and to write poetry and to predict eclipses long before they ever questioned the apparent fact that the sun moves and the earth stands still. Twenty-five centuries ago Babylonian astronomers developed the notion that the earth might be a globe suspended in space, and a Greek philosopher, three centuries later, argued that the earth moved; but very few philosophers during the next twenty centuries could take this speculation seriously. They could not feel the earth move, and they could see the sun move. Yet the fantastic theory of the earth's movement lingered on

in philosophical writings and was considerably discussed in Italy at the time when Columbus was preparing to sail west. Wild as this Pythagorean fancy seemed to most learned people, it appealed strongly to a Polish astronomer who was then studying in Italy. This genius, Copernicus, was equal to the superhuman task of fitting together facts and figures into a proof that the earth spins on its axis every day and travels around the sun every year. Yet because he made one wrong assumption, so that his explanation would not check with all the facts, most scholars continued to laugh at his topsy-turvy theory. During the next two hundred years his proofs carried conviction to very few astronomers. The men who founded Yale and Harvard, like most of their contemporaries in Oxford and Cambridge, believed that the earth was immovable and covered by an immovable "firmament." As late as 1800 there were many cultivated minds that believed it was irreligious to think of the earth's rotating and revolving. Even down almost to our own time the ancient belief was held by many in the United States; in 1880 a colored Baptist preacher of Richmond was still declaring that "The sun do move." His famous sermon was not the vagary of an ignorant negro; it was simply conservatism, only sixty years behind respectable opinion in the foremost American colleges. With such extreme difficulty, after such prolonged controversy, can the human race accept a fact that is not directly apparent to the senses.

In a similar way there was current in the world for two thousand years a speculation that perhaps all animals had developed from earlier and simpler forms, and those again from still earlier and fewer forms, and so on back to a beginning of all life in one lowly species. But this was sheer conjecture. Not until

some genius could assemble a vast array of facts, clearly organized as an argument, would the scientists accept so curious a belief. This feat was performed in 1859, when Darwin's *Origin of Species* was published. So revolutionary a theory was bound to meet with opposition; but the argument was so thorough, and leading students of nature were so well prepared for it, that it soon convinced the scholarly world. Today evolution is universally believed by scientists* and is regarded by zoologists and botanists as the fundamental truth on which all their investigations are based.

*See the quotations in Part Three.

CHAPTER II

THE MYRIAD FORMS OF LIFE

How many kinds of animals does an ordinary person, intelligent but untrained, know about? We have an answer in the works of Aristotle, as observant and intellectual a man as ever lived. It is probable that he was not acquainted with more than five hundred* species; it is doubtful whether many persons ever see in the region where they live more than two hundred species. I once asked a capable boy, who had studied a little school zoology, how many kinds of beetles he thought there were in the world; his answer was "about three in every country." The right answer is "about one hundred thousand well-defined species, plus a greater number of sub-species or varieties."

The contrast between those two estimates is a fair index to the experience that every naturalist has as he grows in knowledge. The few common forms that meet his eyes near his home increase continually as he sharpens his sight and lengthens the radius of his collecting. The revelation, I remember vividly, came to me in this fashion: I was set the school task of making a collection of twenty-five kinds of beetles; this seemed quite an undertaking, for I could not count above a dozen kinds that I knew, most of which I called "bugs"—potato-bugs, tumble-bugs, lady-bugs, June-bugs and so forth. But as soon as I opened my eyes, the new species appeared at every turn of the

*Weismann says two hundred, but the index to the treatises on animals contains at least four hundred.

road, on every flower, under every bit of bark; the text-book by which I had to classify them named hundreds that I might never see; I learned of a mathematics teacher who had gathered for his amusement five thousand species; I saw eighteen large volumes that were entirely devoted to the beetles of Central America; I found that the world was swarming with myriads of beetles in endless varieties.

Beetles, to be sure, are exceptionally numerous, but they are a fair illustration of the incredible numbers of varieties that you would learn about if you devoted a few years to the study of any family of animals or plants. This is the great preliminary fact that any one must realize before he can enter upon an understanding of evolution. The first step of explanation for a John Doe must be to show him, in some kind of panoramic view, how the forms of life branch out into thousands and tens of thousands and hundreds of thousands of distinct species.

In this chapter we need not define formally what is meant by "species," except to say that it describes one sort of plant or animal that has some distinct difference in its anatomy from all other sorts, and that usually can not cross or breed with other sorts. For example, cabbages and Brussels sprouts are not called two different species, because they are so similar in structure; all our domestic dogs could be called one species; all kinds of field-corn and popcorn are one species. But the grizzly bear and the polar bear are distinct species; a pocket gopher from Kansas and one from California, though they look and act much alike, have to be classed as two distinct species. With such a free-and-easy notion of what a species is, we may now take a flight over the world of life. It will be most convenient to follow an order from the smallest and simplest plants to the higher animals.

Photograph, from a highly magnified glass model, of an animal which consists of only one "cell" (see page 99). You are composed of 26,000,000,000,000 cells, each of which, though not so showy, is as intricate a structure. This picture, like most of the others in the book, is made possible by the care and artistry and generosity of the American Museum of Natural History in New York City.

A bit of the Great Barrier Reef off the northeast coast of Australia, where Huxley made his first nature studies. It is 1250 miles long, in places 90 miles wide and 1800 feet deep. It is composed of the skeletons of tiny coral polyps.

Wherever life is abundant in the world, every foot of space teems with invisible plants called bacteria. Some of these are so small as to be beyond the reach of the most powerful microscope, and are guessed at only by their effects in producing disease. Some are so short that fifty thousand of them if placed end to end would reach only one inch, and these are two or three times as large as the germ that is supposed to produce infantile paralysis. Bacteria multiply in such excessive numbers that the mind reels before the figures. For instance, it is estimated that each human being is daily assisted in the digestion of his food by several trillions of these organisms. Nor must we forget that every individual of the trillions is a highly complex being which digests food by intricate chemical processes and which reproduces itself by a mechanism that is so subtle and complicated as to be beyond comprehension. Bacteria are everywhere, living in the most varied ways. They (and closely related fungi) cause all the decay in the world and produce most of the contagious diseases. Upward of fourteen hundred species have been described.

There are ten thousand* species of microscopical algæ that produce slime, and six thousand more that produce a muddy deposit, the exquisite "diatoms." There are four thousand species of sea mosses and kelp. There are more than fifty thousand species of those fungi that we know as toadstools and mildews and smuts.

It would be of little use to continue to set down rows of astonishing figures, for the mind can not conceive them nor retain them. But it is of the greatest use to appreciate, if only dimly, something of the extent to which lowly forms of plants are diversified.

*The numbers of botanical species are taken from Ganong's admirable *Textbook of Botany for Colleges.*

Even so brief a glimpse as this at the wide expanse of life sets the mind to wondering, "How did it all come about? Why should there be so many different ways of living?"

How many kinds of mosses have you ever heard of? If we had never seen but ten kinds, we could rest with the supposition that they were originally created so; but when we learn that there are sixteen thousand species of these inconspicuous growths and that the more common of the species have varieties that grade off insensibly into varieties of another species, then we can not be content with any such guess at the cause. The more a botanist becomes familiar with the countless varieties of plants, the more certain he feels that he is dealing with some sort of continuous growth of the whole system of organisms. A few dozen different ferns would never have excited a Wallace or a Darwin to cudgel his brains for an interpretation of nature; but the four thousand five hundred species that botanists now know might well cause an inquisitive mind to lie awake at night.

All told there are about one hundred thousand species of this lower division of plants. Of the higher division, the flowering plants, there are more than one hundred and thirty thousand species. Some of the items that make up the total are five thousand grasses, one thousand palms, two thousand lilies, seven thousand orchids, one thousand two hundred cactuses.

More significant than mere numbers is the way in which plants unlike in appearance are found to be alike in their anatomy and way of growing, so that kinds which are very dissimilar in all outward appearance are found to have inwardly a decided family resemblance. Thus elm trees, fig trees, nettles and hops are found to have such a similarity in their flow-

ers that they belong together. The figs include such apparently unlike plants as the rubber tree, the banyan and a vine-like parasite. In another great group the botanists have been obliged to lump together geraniums, flax, oranges, mahogany and castor beans, because they are similar in their ways of propagating. The scientists have no desire to do queer things; they would much prefer to say that rubber trees and milkweeds are alike because of their milky sap; simplicity has always been their aim. But nature has made it impossible for them to find any simple way of classifying. It is as if she had strung the most diverse forms on one thread of structure, and had then so looped and tangled the thread that the botanists are taxed to their wits' ends to straighten it out in anything like orderly sequence. When a man has labored for thirty years at this effort to untangle related forms, he comes to think of plant life as a labyrinth, and he demands a clue. What will guide him? His work would be easier if he could discover that all the crisscrossing forms were originally created as distinct kinds of organisms, but the opposite conviction is continually thrust upon him—namely, that these forms are a jungle of variation, that all plant life has forever been altering in character, putting out changes here, there and everywhere.

The puzzle would not amount to much if a species were always a species—if, for example, a certain kind of pine tree were everywhere the same. But within any species there may be endless variations, some of them amounting to striking differences. A grizzly bear, for instance, would seem to be very different from a cinnamon bear; but grizzlies have been found that shade by slight degrees of color and size toward cinnamon bears, and a series of cinnamon bears could be arranged that shade off in color and size to meet

the series of grizzlies. No sharp line can be drawn, and hence some scientists have called them all one species.

Another illustration of the endless variegation within a species is a certain small grass, growing commonly in the United States and Europe, *Draba verna*; when samples of this are gathered from different parts of the world, it is found that there are many distinct types—no less than two hundred have been counted, each of which will breed as true to itself as a Baldwin apple or a Boston Bull. Each of these types, the so-called "varieties," might be called a species. And any naturalist who cares to cultivate the varieties can breed new ones; he can, as it were, watch the plant branching out into new forms. So with wheat: one acute observer counted in a field no less than twenty-three varieties which would, if separated and cultivated by themselves, continue to produce the twenty-three types of plants. A botanist in Amsterdam once counted seven hundred varieties of hyacinths. It is estimated that American florists have caused fifty species of irises to branch out into one thousand five hundred distinct varieties; that they have developed as many forms of roses; and that there have been produced in the gardens of the world no less than eight thousand varieties of roses. So endless are these variations that botanists have no power to tabulate them; one of the most famous, the Dutchman de Vries, says of hawkweeds, "Thousands of forms may be cultivated side by side in botanical gardens, exhibiting undoubted differentiating features, and reproducing themselves truly by seed."

What shall a naturalist conclude after he has spent studious decades in watching these ceaseless fluctuations of countless forms of plant life? What shall he think when he takes stock of this medley of life,

this unmapped chaos of contradictions and relationships? He has no chart or compass until he adopts the evolution theory; with it he can always steer a course.

The same remark applies to the zoologist. If men had never known of more than five hundred kinds of animals, they would not have realized that chaos exists and would have laughed at evolution. Down to 1700 the knowledge of the diversity of life was so meager that naturalists did not recognize any mystery. Even after Linnæus had been compiling data for thirty years—and no more industrious, capable classifier ever lived—he could learn of hardly more than four thousand* species; he would never have felt impelled to solve a mystery in 1758. But by 1858 the situation was entirely different; Agassiz then calculated that one hundred and thirty thousand species were listed, and many discerning zoologists began to fear that they were all at sea. Within thirty years from that date the count had more than doubled; and twenty-five years later had almost doubled again—that is, a conservative count had reached 522,000 species. If by that time (1912) the zoologists had not had the aid of the evolution theory, they would have been swamped by the mounting billows of species and sub-species.

To say that in 1912 there were listed in scientific libraries 522,000 species of animals is like speaking of billions of dollars in a public debt—we can not comprehend such a tremendous sum. No more can we have a comprehension of the numbers of animals until we dwell upon a few of the details. One of the smallest items illuminates the whole subject strikingly: fifty years ago only thirty species of deep-sea

*Most of the following figures are the estimates of Professor H. S. Pratt of Haverford, in *Science*, March 22, 1912.

fishes had been seen; now there have been dredged up and accurately described more than one thousand species. Linnæus, the great father of classification, whose fame is still bright, could count only forty-one species of worms; there must be 8,000 known to-day. We now know of 2,500 kinds of sponges, 16,000 of spiders, 3,500 of reptiles, 61,000 of mollusks. Collectors have penetrated the wildest quarters of the globe, have braved the desert heat and the arctic ice, have searched the mountains above and the ocean below; everywhere they have discovered new species by dozens and hundreds. Whereas Linnæus could count only 444 kinds of birds, we know of over 13,000. He listed only 183 mammals; at present we have accounts of some 3,500.

These figures were compiled by Professor Pratt in 1911, and may be ten per cent. under the totals that could be reckoned to-day. If any of the figures are too high, we may be assured that before many years they will be too low; for they are being augmented almost daily. L. O. Howard, one of our greatest entomologists, has said that the number of insects now known may ultimately be multiplied by ten. Men who, like him, have spent a lifetime amid the rising tide of numbers would yawn at our little lists of the hundreds of thousands; for they do not think in terms of arithmetic, but in one term—of a flood of varied life.

And this flood of life now in the world is only a small pool when compared with the ocean of forms that have, during the long history of the world, risen and flourished and become extinct.* The geologists are familiar with limitless reaches of changing life that stretch through the millions of years of the geo-

*The long record of the prehistoric life of the earth, perhaps covering five hundred million years, is outlined in Chapter XII. It furnishes stronger evidence than the study of the forms now living.

logic ages, glimpses of which may be seen in the fossils. Even the fragments of this ancient history, when pieced together in a list, reached, twenty years ago, the respectable aggregate of eighty thousand species of vanished life. The great naturalist Wallace believed that in the whole past history of extinct forms of animals there "*must* have been thirty or forty times as many species as are now living." He guessed that *probably* there have been on the earth in all its different periods "many hundred times as many species of plants and animals as now exist."

So boundless, to the gaze of a scientist, is the realm of life which we amateurs have tried to skim over in one brief chapter.

CHAPTER III

THE TANGLED WEB OF LIFE

THERE is nothing baffling about mere numbers of species. If the naturalists had never been confronted with any problem more puzzling than half a million or a hundred million species, they would never have been driven to seek out an evolution theory. The previous chapter gave several indications of the real mystery: the tangle of forms. Only a lifetime of experience would give a partial conception of the endless series of kinds that shade gradually into other series of kinds. In this chapter we can do no more than view, as from an airplane, distantly, a few of the thousands of bewildering facts known intimately by scientists.

In the previous chapter we got very little suggestion of any bewilderment. We saw neat packets of "one thousand two hundred kinds," of "three thousand five hundred kinds," of "sixty-one thousand kinds." The inference was that a biologist could tell two distinct species as easily as a stamp collector can decide that two bits of printed paper are not duplicates.

The fact is just the contrary. Professors Pratt and Ganong would be the first to admit that no count of species can be made, that their lists represent only the roughest approximations to a set of balances of opinions. Until a reader understands that statement he is not on his way to a comprehension of evolution—

any more than a detective could find a criminal before he knew what the crime was.

What is life? The more we study it, the less able we are to give a definition. If an invisible bacterium is an individual plant, why is not a white corpuscle in our blood an independent animal? And if a white corpuscle is a separate creature, how shall we draw the line between it and a cell in our muscles? If these self-propagating cells of our flesh are animals, why is each self-propagating cell of a leaf not a plant? We can not tell where individual life begins.

As soon as we pass upward from this doubtful region of cells at the basis of all life, we are at a loss to know the difference between the lowest plants (Protophyta) and the lowest animals (Protozoa). The voice of science can only admit that "no hard-and-fast line can be drawn around Protozoa to distinguish them from Protophyta." It declares that "the formal distinctions between the animal and the vegetable kingdoms have vanished, and in their place we have an intimate, unbroken continuity."

So at the very beginning of any examination of the world of life it appears that all is confusion. The naturalists could never arrive at any understanding of this vast tangle until they found some one principle that would account for all the variety of the strands and for all the interweaving of them. All our observation of nature shows that nothing ever happens by chance, that every object we see was fashioned by undeviating law. Hence any naturalist in his senses must suppose that every least filament in the web, every variation of form, every continuous series of forms, became what it is by the operation of some fixed, unvarying forces. Just as our minds are obliged to think that there must be definite causes for rainbows and wireless telegraphy and tides and fires, so

we take it for granted that the various forms of life are not the result of a hodge-podge of unaccountable accidents. Much less can any reverent person nowadays credit the idea that a whimsical Creator amused Himself and befooled His human children by devising a lawless welter of freaks.

The devout and sensible scientists never tolerated such an idea. With one accord they have always assumed that there is some definite method of creation, and they have done their best to discover it.

After 1700 their efforts were based on a certain assumption—a very natural one and very useful. This theory was that all animals were arranged on a "scale of nature," from the low and simple forms to the high and complex. Each degree on this scale was a small but sudden step upward from one kind—called a "species"—to the next higher kind. Thus each species was sharply marked off from the one below and the one above; it was a distinct type of life that had always been what it now is, and that would never be anything else.

The "scale of nature" hypothesis stood the test of experience fairly well in the eighteenth century for classifying four thousand species; it still applies after a fashion; for the species that we observe in nature *seem* fixed.

An account of what the word "species" signified in 1830, and of the controversy about it, is the easiest entrance to an understanding of the evolution theory. Some readers will wish, first, to see a display of the term in its setting in the system of classification that has been used for the last two centuries. For their convenience the following numbered paragraphs are inserted to show the graduated divisions, from large to small. This is not a review of technicalities, but is an approach to the heart of the subject.

The nature of classification. To begin with, what are the scientists about, what is their purpose, when they "classify"? They are only doing what we all have to do in our private affairs when we arrange *or sort out* a lot of articles that are in confusion. No business office can keep five thousand letters in the same order in which the postman brought them; they must be sorted—that is, classified—alphabetically or by their subject-matter. A carpenter must classify his tools and nails and screws, else he could never put his hand on what he needs; a college must classify its students as failing, passing, doing fairly, or doing excellently; if the people in a city were not classified by names and streets, all general business would come to a standstill. So the scientists would be all at sixes and sevens unless they carefully classified their huge stores of facts. One example will bring this home: thirty-five years ago the manuscript of the catalogue of plants kept at Kew Gardens in England weighed a ton.

1. Kingdom. A vast labor the classification has been, and is still very incomplete. A glimpse at the nature of it can be had most easily by noticing how the first ancient classifier went to work. He began, as any shrewd man would after some observing and meditating, by dividing all life into two "kingdoms," vegetable and animal; and the scientists still follow this primary division.

For the first subdivision of animals Aristotle found that he could make two great groups, according as they had or did not have a backbone. Among those with a backbone he naturally made sub-groups of those that walk on four legs, those that walk on two legs, and those that live in the water. Then his troubles began; for a man walks on two legs, but is unlike all the birds in not being covered with feathers.

Classification is a task that demands the highest analytical skill and patience. To this day the zoologists are agitated about the shortcomings and contradictions of their system of sorting into orderly groups all the known kinds of animals.

2. Phylum. With their elaborate details we have no concern, but we do need to know their principal terms. In beginning an arrangement of animal life they first try to put together in large groups those sorts that are similar in some general way—for example, all the backboned animals are grouped together into a "phylum." In another great phylum are lumped together all such "jointed" animals as insects and lobsters.

3. Class. Within each huge phylum many subdivisions must be made—for example all the lobsters and crabs and barnacles are put into one "class," all the spiders into a second class, all the insects into a third.

4. Order. Insects are such a vast horde of dissimilar forms that they must be subdivided many times before there will be any practical classification; they are sorted into twenty "orders." One of these orders includes all the beetles.

5. Family. It is clear that classification has only begun. The order is divided into great groups called "families." The largest family of the beetles, for example, is the snouted weevils.

6. Genus. This family, like every normal one in the plant or animal kingdoms is subdivided into groups, each of which is called a "genus" (plural *genera.*) One genus of weevils, named *Anthonomus,* includes many sorts that make a specialty of living in buds and pods; its members are spread over the whole globe. Classification is always that same operation of making narrower and narrower divisions of groups whose members are somewhat alike, sorting

out those that have closest resemblances into smaller and more homogeneous groups, and then again sorting each smaller group into sections that are most alike.

7. *Species.* Such a subdivision of a genus is called a "species." A species is the last complete stage of the sorting process; it is such a narrow division that all the members of it bear a close resemblance to one another and can usually mate together; whereas the members of two well-defined species can rarely produce fertile offspring. *Anthonomus* contains one world-famous species, *grandis,* which has destroyed billions of dollars' worth of property for the cotton-growers—the boll weevil.

8. *Variety.* It often happens that within one species there are many somewhat different forms, which can be accurately defined and which breed as true to type as distinct species; these are called "varieties."

When we consider that such an exhibit of classification, though it extends through eight paragraphs, does not represent an outline of the scheme of even four thousand animals, we have a faint suggestion of the interminable maze of nature, and of the struggle which the eighteenth-century naturalists had.

This struggle centered on one point—on the theory that species are unchangeable. The reader must center his attention on the same point, for it is the approach to the whole subject. A species, as the eighteenth-century classifiers conceived it, was a certain kind of plant or animal that never had been and never could be different. Linnæus believed that a species was an unchanged and unchangeable unit of life. His own words were: "There are just so many species as in the beginning the Infinite Being created."

If this had been true, the course of natural science would have been smooth. The zoologists would sim-

ply have had to detect these eternal kinds of life and count them up as astronomers have counted the stars. Great was their amazement to discover, long before 1800, that they could not agree on how to distinguish. They all wanted to agree; they all took it for granted that agreement would be possible. But with the years the disputes increased. Even Linnæus had qualms when he found how often a dividing line was difficult or even impossible to draw. By 1800 a Frenchman (Lamarck) had denied that such divisions could ever be made successfully, because as the stores of facts rapidly increased he saw the tangled web grow ever more tangled. He put the case thus in the very year of Darwin's birth, 1809: "The supposition generally believed—that organisms are arranged in 'species' that are always distinguishable by invariable characteristics, and that the existence of these species is as ancient as nature itself—was established at a time when men had not observed enough and when the natural sciences as yet hardly existed. It is always belied in the eyes of those who have seen much, who have long attended to nature, and who have studied with profit the large and full collections of our Museum."

Around the conception of species the battle raged. In France and Germany and England there were plenty of learned men ready to abandon the idea that a species was a fixed fact of nature. But if they had done so, where would they have found themselves? Floating in a fog of philosophy. It might be all very well for a reckless, imaginative Frenchman to abandon facts and speculate about all life as a continuous stream of forms that changed into one another. But that was to deny their own senses, for they could see a multitude of fixed species, and Lamarck could not show them one that changed into something else. Why should they give the lie to their own eyesight? They were like Romans who were asked to believe that the

sun stood still and the earth moved. They decided—and quite sensibly—not to follow such vagaries of philosophy until some tangible evidence was forthcoming. It did not come. No one could find any proof for Lamarck's fancy. By 1850 it was considered unscientific and foolish to discuss any evolution theory. The fixity theory was more firmly established than ever.

The scientists were, nevertheless, perpetually uneasy, at a loss, discordant among themselves. For they could not mark the limits of the species that they believed in. It was a curious dilemma. If a man believed that species were variable, he was beyond the pale of realities; but if he believed that species were fixed, he could not lay his hand on the realities. Either way he was lost and baffled in the tangled maze of living forms.

"What is a species, anyhow?" was the constant query. Darwin often reveals in his letters what all scientists felt, but could not well give vent to in their formal publications. He wrote in 1849, when trying to classify the barnacles: "I can not at present tell the least which of two species all writers have meant by the common *Anatifera lævis*. Literally, not one species is properly defined." In the same year he wrote to a great botanist: "I often feel wearied with the work, and can not help sometimes asking myself what is the good of spending a week or a fortnight in ascertaining that certain just perceptible differences blend together and constitute varieties and not species. . . . I have just finished two species which possess [*i. e.*, in the different works of reference] seven generic and twenty-four specific names!" Seven years later he wrote again: "In some naturalists' minds resemblance is everything, and in some resemblance seems to go for nothing; in some sterility is an unfailing test, but with others it is not worth a farthing. It all

comes, I believe, from trying to define the undefinable."

Huxley thus describes a bit of the dialogue when, as a young man, he had his first interview with Darwin: "I expressed my belief in the sharpness of the lines of demarcation between natural groups, with all the confidence of youth and imperfect knowledge. The humorous smile which accompanied his gentle answer, that 'Such is not altogether my view,' long haunted and puzzled me."

No wonder that Darwin smiled, for he was familiar with facts like these: "As soon as these three forms, which had previously been ranked as three distinct genera, were known to be sometimes produced on the same plant, they were immediately considered as varieties; and now I have been able to show that they are male, female, and hermaphrodite forms of the same species."

Wallace pictures the situation vividly in this sentence: "All students were so impressed with the belief in the reality and permanence of species, that endless labor was bestowed on the attempt to distinguish them—a task whose hopelessness may be inferred from the fact that, even in the well-known British flora, one authority describes sixty-two species of brambles and roses, another of equal eminence only ten species of the same group."

The first authority had "split" the roses into sixty-two species; the second had "lumped" them into only ten. This case is typical. The same tendency is as strong as ever to-day: if a naturalist is keenly interested in noting slight differences, he will find many species and be a "splitter," if his mind works on the other tack, he will be a "lumper."

In a recent study* of a genus of crickets the au-

*F. E. Lutz, *Carnegie Publication 101.*

thor tells us that six species have been commonly described, that one man lumped these into two, that another man lumped them into two by a different grouping, and that the author thinks there is only one species.

If we should search the classifications of the ants, as made by all the splitters, we might count six thousand species; if we took the records of the lumpers and selected the lowest list from each, we might have no more than two thousand.

Any amount of similar evidence could be cited to show that a species is essentially an opinion. If a very careful man makes a prolonged study of a certain genus, and if succeeding students think well of his judgments, his opinions stand as named species; if his judgments do not stand the test, they are set aside by the next student. Illustrations like this from the *Britannica* article on wolves can be found very frequently in common books of reference: "These differences have given rise to a supposed multiplicity of species. . . . But it is doubtful whether these should be regarded as more than local varieties." Indeed all the efforts of all the authorities to assort wolves and dogs and foxes and jackals have failed to produce any generally accepted scheme of species.

A pretty demonstration of the whole species puzzle is exhibited in the American Museum of Natural History. A circle of fifteen tiger beetles is so arranged that the distinctive markings of one species, shown fully in the first specimen, are slightly different in the second, somewhat more different in the third, and so on, until when we have gone the round we find that the fifteenth specimen, next to the first, has the markings of another species.

Truly the works of nature appear as cycles that merge into other cycles, and these loops are combined in a tangled web of life.

CHAPTER IV

THE VARIED MODES OF LIFE

When I, with my untrained eyes, pay any attention to plants, they seem to be very regular, uniform things. A buttercup seems like all the other buttercups; an acorn seems to produce the same kind of oak that it fell from; a housefly or a June-bug is always of the same size and has parents and children that are exactly like itself; a sea-gull never mates with a hawk; everywhere I go there are a lot of buttercups and flies and hawks and ants that are just the same as the ones I have seen before; an oyster is never an eel. So far as I ever noticed, all forms of life are well separated, distinctive, uniform. I never see any puzzle or any need of worrying about classifying.

And so long as I do not see any puzzling irregularity, I can not have any interest in evolution or take any stock in it. Every naturalist would have been as indifferent as I am if he had always remained as ignorant as I am. No person will see any sense in evolution until he knows at least a little bit of the endless confusion and crisscrossing and interlacing of the kinds and modes of life of plants and animals.

So it is time to describe a few of the puzzles that every biologist meets with. If you find this chapter somewhat bewildering, you are on the road to understanding; for you can then see, in some slight measure, what the scientist's problem is. This chapter does not explain anything. It takes you to a maze of facts

This 12-inch African antelope (a dik-dik), only a foot high when full-grown, is a near relative of the 800-pound Eland antelope. The tropical leaf-hoppers are bugs whose heads have developed into great crests as long as the bodies.

Two strange creatures from Australia. The green phalanger, above, is the only known animal that has greenish fur. The duckbill is the only species in its family; it has thick brown fur, a bill like a duck, and lays eggs like a reptile.

and says, "Look at this, and this, and this. See what the scientist has had to explore and find a clue to. Notice that the facts are interlaced and perplexing."

In this and the following chapters we are going to take the course that Darwin's mind covered in his twenty-five years of effort to solve the mystery. It is as if we, in an express train, whizzed at a mile a minute through the jungles where he had to hack his pioneer way foot by foot. As you glance at the few dozen illustrations in this chapter, try to imagine what they would be like if they were multiplied by a thousand and if your life depended on working out some theory that would bring them all into a neat and orderly arrangement.

I. Groups Are Big and Little, Flourishing and Dying

If I say to a man who has never pondered on the mystery of life, "This yellow-flowered weed belongs to a genus *(Senecio)* in which there are 2,300* species," he may think of a greenhouse where there are 2,300 flower-pots—or he may think of nothing. He does not feel that there is any puzzle about it. "Lots of kinds of weeds?" he replies. "I should say so. Weeds flourish everywhere." But ask him to imagine how a botanist understands the statement. To the botanist there is no such thing as the difference between a "weed" and a cultivated plant. He knows them all alike as plants that have to fight for a living in the soil. When he hears of a genus of 2,300 species, he recognizes a group that is extraordinarily hardy, that has spread over wide reaches of territory, that has fought its way to victory in many climates, and

*Gager, *Heredity and Evolution in Plants.* Most of the figures given in this chapter are taken from older works of reference; hence they are generally understated, though in a few instances they will be larger than those shown in some recent taxonomic arrangement.

that has branched into 2,300 different ways of making conquests in battles against other plants. He admires it as a mighty and successful kind of organism. He sees it is an adaptable, ever-varying form that flourishes like a very fountain of changeable life.

Show a botanist the opposite kind of picture: "Here is a Chinese tree (the gingko) which is a separate genus all by itself; there is only one species of it." Then he is struck as by a sight of a dying race. He is puzzled as he contrasts it with a group of 2,300 species. Why should it remain so stolid and meager while another race goes victoriously forth in a myriad of guises? One genus seems to sport in lavish, youthful strength; the other appears to be dying. In an orderly universe what should make races come and go?

A zoologist meets the same mysteries of the big and the little groups, the flourishing and the dying. A genus of squirrels in Borneo and another in India have only one species each; of the genus of pigmy squirrels there are a few species; of the striped ground-squirrels there are more; and of the tree-squirrels there are dozens—large and small, gaudy and plain—all over the world. Similar contrasts could be cited without end. The genus of rabbits is everywhere—in the foggy north of Scotland, in Brazil, in the Himalayas—overrunning all countries with its thirty species; whereas the genus of camels is domesticated in a small region and has only two species.

The same contrast of numbers and strength is seen in the "families" of plants and animals. Ordinarily a family is a large group embracing several or several dozen genera. In the sunflower family there are one hundred and fifty genera, and in the great families of animals there may be as many. But some forms of life are so peculiar that they must be made a family

all by themselves; thus there is now living on the earth only one genus of the rhinoceros family.

Those words "now living on the earth" give a hint of the depth of the mystery. The study of fossils shows that forms have waxed and waned through the millions of years of the geologic ages. *There used to be* many genera in the rhinoceros family. A long acquaintance with this flow and ebb of life arouses a suspicion that a large and a small family, a large and a small genus, are not permanencies, but temporary fluctuations; and such a thought is exciting to any scientist who is trying to discover nature's secret. The California genus of sequoias is now limited to two species on one strip of coast, though some millions of years ago it flourished in many species from ocean to ocean. Why should this ancient group have dwindled almost to extinction while the genus of pines was increasing to seventy species that triumphantly made their way to every part of the north temperate zone?

Nor is the mere fact of large and small, flourishing and dying, the most striking feature of what naturalists learn. Their curiosity is more aroused when they find that a chart of their classifications resembles a tree. If a certain order of animals branches into three families, two will probably be small side-branches and one will be like the continuation of the main trunk. If this dominant form divides into twelve genera, one genus will be very small, ten will be moderate in size, and the twelfth will be the large and typical group. It is this dominant twelfth genus that will ramify into a hundred species, and most of the hundred will show more vitality, be more numerous, and tend more to split into varieties, than the species of the eleven small genera. And of those hundred more lusty species there will probably be three that are decidedly more numerous and common,

spreading into more varieties, than any of the others. A botanist expects a map of an order to look like the trunk of a tree, which grows upward in a main stem, the principal family; this family continues in the largest branch, the principal genus; and this genus continues upward in a few sub-branches, the principal species.

II. Varied Sizes in One Group

Among the rattlesnakes there is a species of which a full-sized adult is only eighteen inches long; another species furnishes specimens four times that length. Among the frogs, of the one genus *Rana,* there is a species (*goliath,* from western Africa) which weighs ten times as much as any frog that I ever caught for bait. In India there is a rat with a body that is over two feet long. The paleontologists have found in the family of horses a genus that was only a foot high. In a systematic, man-made world the clams would all be about three inches long; in the world as it is clams range in size from under that standard all the way up to *gigas,* which may be forty-three inches long and weigh nearly six hundred pounds.

There is a parasitic animal so small that it is barely visible when shown in a good light against a contrasting background, and another that is two inches long, armed and armored in a terrific manner for the capture of tarantulas; yet both are wasps. A similar case is the pigmy deer, the dikdik of East Africa, which is only a foot high; it is quite unlike the little mouse deer of Asia, but *is* closely related to the great Eland deer which may weigh more than half a ton.

When a visitor has strolled through a menagerie and a museum, he is impressed by these freakish variations of size; he wonders why nature has sprouted out into all these deviations from a standard.

III. Varied Developments

The boy Darwin, like the rest of us, thought that a frog was just a frog; it was a leaping land-and-water animal that lived and looked like all the other frogs. Not until he was dead had the collectors found any species that was larger than our American bull-frog. How many readers of this book know that some frogs never enter the water except to breed; that one species burrows for its home; that another lives in trees and has a membrane with which it becomes a kind of flying frog; that another species builds nests among the bushes above the water; that another is hairy; that most species have teeth only in the upper jaw, while some have teeth in both jaws, and others have no teeth; that one species in the Solomon Islands has a horn?

We stay-at-homes, who spend our time with bridge and business and novels, never know how, in the most uniform and monotonous genus, nature has modeled surprising species. She is perfectly varied in the most contradictory ways. No person can credit evolution until he sees something of what naturalists are involved in. No uniformity can ever be expected; no rule can ever be guaranteed.

It is a rule, for instance, that animals eat plants and that plants draw food from the soil; and that rule holds for a hundred thousand species, and the next hundred thousand, and the next, and the next. But there is an exception. There are one hundred and fifty species of plants that eat animals. One, in Georgia, has hinged leaves that close on a fly, digest him, and open for the next fly. Another, in Australia, develops some of its leaves into cups that entrap insects. Our American pitcher-plant, of an entirely different order, makes for itself a much more elaborate trap, that is always open for insects and digests them by

dozens. In the Malay Islands there are species of still another order that put a lid on their pitchers.

Rather bewildering, all this, when we consider that these similar and very peculiar devices are found in different *orders* of plants on all the continents. A fanciful naturalist might guess that since the youngest rocks were made, several very different sorts of plants had learned to eat meat; for no such fossil plant has ever been found. It was a mere fancy, an utterly wild and unwelcome one to any steady mind in 1830.

We human beings are apt to suppose that agriculture and slavery are a pride and a shame peculiar to the human race. But go to the ant. There is a tropical species which cultivates the fibrous growths of a kind of toadstool; they have learned to cut off the spore-bearing branches, so as not to let the plant breed and destroy itself. Many kinds of ants keep plant lice, as a sort of cattle, for their sweet juices. Some ants have grown so used to being served by enslaved ants that they are powerless to feed themselves and would perish without the servants.

The more we see of animals, the greater grows our wonder at their varied developments.

IV. Varied Relationships

Most of us remember the mental shock we received when we first learned that whales and porpoises are not fishes, but warm-blooded, air-breathing mammals that suckle their young on the cold ocean waves and that would drown as surely as an elephant if they could not breathe air. So we all learned with a little start that tree-toads are not toads and that horned toads are lizards. Similar contradictions in classification, of a more striking kind, are the stock in trade of every zoologist.

There is an opossum-like creature in Australia, not a foot long, which has a decidedly greenish color —the only mammal known which has fur thus tinged. In Tasmania there is a creature that looks like a wolf, that seems as different from an opossum as a tiger does from a rabbit; yet it is allied to the opossums and is not a wolf at all. The duckbill, which looks like a beaver and is covered with thick fur, has a horny bill like a duck and lays eggs.

Plants furnish many examples of crisscross relationships. Staid old peach trees, with only peach-tree ancestors, have more than a few times been known to send out a sporting branch that bore nectarines. The botanist can not draw any boundary line between peaches and almonds; for a small, hard, seedling peach is very like a green almond in appearance and structure; from these inferior peaches "we may pass by small transitions, through clingstones of poor quality, to our best and most melting kinds." On the other hand an apricot, which seems so like a peach, is by some botanists classed in a different genus, is commonly grown on the stocks of plum trees, and—quite unlike the peach—will grow true from seeds.

No matter-of-fact human brain could ever invent the freakish relationships that are to be found in plant life. Who would have thought of a partnership between two classes? A botanist who had dreamed that plants "learned" to catch insects might believe that his dream was confirmed when he investigated lichens: here are four thousand kinds which are compounds of two different classes of plants, fungi and algæ. The fungi and algæ enter into a very close partnership and provide nourishment for each other. The truths of botany are stranger than any fiction could be.

V. Varied Ways of Propagating

Occasionally there is an intelligent person, with opinions about evolution, who supposes that winged moths eat clothes; he does not know that the moth has for a mouth only a delicate tube with which she could not injure a cobweb. Yet this same intelligent person knows in a general way that there are voracious caterpillars, with powerful jaws, which spin cocoons, in which they become dead-looking pupæ, and from which they emerge as moths with a slender, sucking proboscis in place of the former jaws. Most insects go through these three stages of life. A moth or a fly comes into its third stage full-sized and usually leads a life that is entirely different from its first stage.

The double life is common among smaller animals, in the most extraordinary ways. Many disease-causing parasites live their first stage in one animal and their second in another. They may live rather harmlessly in spiders or mosquitos or squirrels or pigs; then when, by most diverse and remarkable means, they reach a second victim—a cow or a person—their second stage causes a virulent disease like bubonic plague or sleeping-sickness or malaria. Barnacles, after living quietly in a shell for a long time, spend the second part of their life-cycle as free-swimming, soft-bodied creatures.

Some animals reproduce by throwing off buds; some have male and female parts in one organism; in some cases the male individual is a mere minute parasite; some marine species seem to be male or female according to the accidents of their life. Plant lice breed for a long series of generations as females only, without any pairing; then comes a generation that contains males, and there is pairing of the sexes. Among the plants are to be seen all manner of combinations: one sex only, two sexes in one plant that

mate in that plant, two sexes in each plant that can mate only with the sexes of another plant, only one sex in each plant.

Why should nature, that stern and steadfast mother, thus toy with ways of propagating that seem so wantonly varied?

VI. Varied Heredity

We have been taught that like breeds like. We know that a grain of mustard seed will produce a mustard plant, that an eagle's egg will yield an eagle. Surely, if there is any way in which we might suppose that nature is unvaried, it is in this matter of like producing like. If I walk through a patch of wild roses, they look alike to me; the ones I see in Maine seem like the ones in Iowa and California.

But a florist, who has eyes to see, detects the differences. He knows that roses are very unlike, fluctuating in size and tint and odor. Put him into a field, and he will cull you out a dozen unlike ones, will plant their seeds, will cull again from the second generation those that are more unlike, will continue for several generations, and will then show you a "new" rose, such as the sun probably never looked on before.

To my dull eyes the sheep in a flock are very much alike, but a shepherd knows them individually and calls them by name. Probably I could not tell one ant from another if I studied them under a microscope, but an Huber knows them apart as if they were children of the neighborhood; he names them and recognizes their mental peculiarities. Like never does beget precisely its like.

And yet it is obviously the rule of nature that like *tends* to produce like; ordinarily an animal is like its parents, as they resembled theirs, and so on back through ten generations; we know by specimens in

our museums that potato-beetles of a hundred generations ago are like those that we spray to-day. If Huber had lived a thousand years earlier, he would have seen similar ants with the same individualities. Indeed the tendency to produce similarity seems strongly preponderant; for if the florist's artificially selected roses were put back into a state of nature, they would soon recur to the ancient type. If crossings are made between two of our artificial domestic breeds of fowl, the offspring may show a strong tendency to revert toward the natural form that they had several thousand years ago when they were wild on the slopes of the Himalayas. Like does tend to produce like.

This contradiction in heredity is an illustration of all the paradoxes woven into a web that hid the secret of nature from the prying eyes of science. It was this woof of contradiction and variation that young Darwin had before his eyes when, like Siegfried before the wall of flame, he girded himself to penetrate the veil. He indulged in no such heroics about matching his intellect against the secret of the ages; but, after he had been around the world observing the varied forms of life, dedicated himself to the struggle in these simple words: "It occurred to me that something might perhaps be made out on this question by patiently accumulating and reflecting on all sorts of facts which could possibly have any bearing on it." Not till he had spent twenty-two years in accumulating did he allow himself to publish. Then his *Origin of Species* opened a wide gate to knowledge, through which all men might walk and view a most remarkable revelation.

CHAPTER V

THE JUNGLE OF ADAPTATIONS

In the last three chapters we have been taking glimpses at the mazes of life, and in this chapter we shall continue to do the same. There is no explanation here. We are going to look at a mystery, one at which men have always marveled and for which they have spun various theories out of their imaginations —the devices that enable living creatures to obtain a living.

Every plant and animal has its own way of succeeding in its struggle to live, is fitted for getting food and competing with its rivals by a peculiar anatomy and a particular set of instincts. All such adjustments for the fight of life are called "adaptations." Their enormous number and variety, in an endless luxuriance of competing series of devices, are only feebly indicated when likened to a tropical jungle.

The woodpecker is adapted for preying upon insects that live under the bark of trees: two of its long sharp toes grow backward and two forward, thus forming an instrument for grappling the surface of a tree; its tail-feathers are spiked to give a purchase for the toes and are like a spring to help the hammering operations; the bill is a beautiful chisel; the skull is, unlike that of any other bird, so contrived that the rapid succession of resounding blows on the wood can be delivered without racking the head to pieces. This bird is adapted for its life-work. It could not

live by wading or by searching for carrion or by diving in water, but is contrived to be a highly successful hammerer. Even a heedless mind is struck by this arrangement. Even a dull mind naturally asks, "How did it all come about?"

Every child knows of the adaptations of animals for fighting and for defense: the rhinoceros is armed with terrific horns; the wasp has a most elaborate sting and poison gland; a Brazilian eel is equipped with an electric battery that can give powerful shocks; the skunk and the pinacate beetle emit offensive odors; the sword-fish is armed with a combination battering-ram and spear that can pierce the planking of ships. Whence came these adaptations?

Nature-books picture the adaptations of the camel, which is fitted for its desert life by the thick soft cushions on its feet, by the hump where food is stored, by the tanks in its body where water is stored, by its power to digest dry shrubs, by its power to close its nose when a sandstorm is raging. So complete is the adjustment of these parts of his body that the beast can carry a rider two hundred and fifty miles across the sand in five days without a drink. How were all these devices assembled in such a partnership for enabling camels to live in the desert?

The equipment of some animals is so extraordinary that a description sounds like a fairy story. There is a small fish, living in the utter darkness two miles below the surface of the ocean, which makes its own light that shines out through port-holes along its sides, and which sees through eyes that are perched on the end of long stiff tentacles. There are birds that hatch out eggs when the temperature is twenty below zero. There is a Malay plant with a blossom three feet wide which, when it is ready to be fertilized, makes an odor like tainted meat, and thus attracts the

The Tasmanian "wolf" is not a wolf at all, but a marsupial, like the kangaroos. The Panda, which looks like a bear, is related to the raccoons.

The Koala, one of the many kinds of Australian marsupials, looks like a bear and has grasping toes for its life in eucalyptus trees.

flies that will bring the needed pollen from other similar plants. These examples are not extreme. Stranger ones can be found in books that treat of the wonders of nature—for example Fabre's accounts of insects.

If you ask a Malay savage why the big red blossom has this queer power of making a bad odor, he may tell you a myth of how some angry spirit designed it. Ask an American business man, who has spent his life in trolley-cars and Pullmans, and he will say that the blossom was designed that way—that's all there is to it.

But ask a man who has long been curious about the odors of flowers, who knows all about these adaptations, and he will shake his head and talk like this: "It's too much for me. If there were in the world only thirty-four odors of flowers, and if each were an adaptation peculiar in itself, I could let it go at that and bother my head no more about it. But the longer a man trains his nose in this study of mine, the more he finds out that there is no sharp distinction between one smell and the next. No flower has any special adaptation of odor, but every one blends into its place in the whole long array of all the odors.

"It's like a spectrum of colors—you know, the rainbow band that is made when a beam of sunlight goes through a prism. If I stick a pin here in the band and another pin half an inch farther up, I can see the difference between the orange and the yellow colors. But if I start at the first pin and move my eye along only one thirty-second of an inch at a time, I'm not sure whether I can see any difference; the change is so gradual and blended.

"That's the way it is with the flowers. If I made up a row of fifty thousand species, starting at the bottom with our friend from Malay and putting next

above him one from Brazil that isn't quite so offensive, and on top of that an Abyssinian specimen a trifle less rank, and so on, and so on, until I reached no odor at all, and then continued my graduated scale on up through very slight odors, to violets, and up to mignonette, and on up to tuberoses, then I should have a continuous spectrum of odors, all grading into one another. And that is not the strangest fact. The plants in my arrangement for odors would not correspond to the botanist's classification, but would cut across his groupings like the shaft of a mine through all the orderly layers of rock. The more you learn about odors, the more they seem like one continuously varying stream of adaptation."

If you ask a student of birds, "How were a woodpecker's adaptations made?" he will smile at the ignorance behind the question. To him you are like a child who has heard about Franklin's kite and wants an explanation of lightning in words of one syllable. "Yes," he answers, "the woodpecker's feet and his spiked tail are beautifully designed for life on a tree —if you never leave the United States. But in Argentina and Africa there are woodpeckers, with all this equipment, which never light on a tree. Their beautiful adaptations are utilized for making nests in clay banks!"

He pauses to see what effect his sarcasm has produced on us. We catch our breath and murmur something like, "Well, we thought that a clear case of design like this—"

"Oh, you *thought*," he interrupts. Now he is irritated. "When you learn about some little quaint adaptation, you *think* about it. You *think* how ingeniously nature contrived it. You *think* that nature is a humorous artisan, like a Nuremberg toymaker, sitting in her shop and designing animals by fixed

patterns. You ought to be ashamed of yourself. What business have you to insult nature and your own common sense by talking as if there were only fifty-seven varieties of birds, and as if a woodpecker was always a woodpecker, and as if you had named a patented, machine-made brand of invariable anatomy when you say *woodpecker.*"

We can't understand his earnestness, but we want him to keep on and reveal what is in his mind. "I tell you," he continues, his voice rising, "that you have no conception of what you say when you let that word *woodpecker* slip off your tongue. There are three hundred species of them, of all sorts, and their adaptations blend into one another so that they seem like a crooked current of adjustment, sometimes running smoothly and sometimes dammed and thrust out of its course; and they crisscross one another so that it passes the skill of man to classify the freaks of adjustment. Perhaps you are so observant that you know a red flicker from a yellow flicker. What would you have done if you had been with me a few years ago in Montana when I tried to untangle the mixtures of these two strikingly different species? What would you guess about adaptations if you found that a certain species was all duly fitted out with spikes on its tail, but that it couldn't use them because the tail-feathers were too limber? Perhaps you would judge that Dame Nature was having some fun at the expense of the poor bird, or that she made an error that time. You talk about the toes. Why, any quantity of birds, quite outside the woodpecker family, have that same arrangement of two toes before and two behind; but one genus of woodpeckers is *not* built that way. What's more, some of these 'yoke-toed' birds have the first and fourth toes turned back, while others have the first and second turned back. What do you *think* about those adaptations?"

"Well, surely, Mr. Bird Man, you can't blame us ordinary people for thinking that any one yellow-hammer looks as if it was designed."

"No, I don't blame you. I needn't have talked so fiercely. Why, the fact is it used to seem that way to me. I was like any savage. When he hooks a big fish, he apologizes to it and prays, because he *thinks* there is a spirit in it that will take vengeance on him. He thinks that everywhere in nature there is human feeling, human purpose, human planning and adapting. And we civilized people are just like him. When we see a bird's toes adapted for clinging to the bark of trees, we ask *who* did it. We and the savage always think of a personality.

"When an Indian sees the sun moving across the heavens, he supposes that it is somebody, and he figures out who puts it to bed every night. He sees adaptations of plants, and naturally supposes that some mind—a little more clever than his own and more cruel—planned all the queer devices. He can't think any other way. He has to see all nature revolving around his little human brain. But the fact is that nature is the big central force, and it is more powerful and more remote from our poor thoughts than we can conceive. It doesn't do any petty tinkering in a shop. It works in just an opposite way, in a great and simple and dignified way."

"Quite a revolution that was in your savage mind, Mr. Bird Man. What missionary rescued you?"

"Facts! You know that if you wanted to tell a South Sea Islander about the sun, you would first have to teach him to count ten, so that he could learn to see how many pebbles there are in ten piles of ten pebbles each. And when you had trained him to count ten thousand, you would then have the long job of trying to make him realize what a temperature of

five hundred above zero is. You would have to educate him gradually in a few simple facts and try to give him a picture of some globe that is bigger than his island and farther away than across his lagoon. Even after years of your best training he will find it hard to credit a distance so great that the steady flight of the swiftest bird would not cross it in a century. How can he ever believe that gravity acts on our earth through such a space? I'll confess I sympathize with him. The way nature makes adaptations is—well, it's hard for us humans, on our little island of the universe, to take in. You never will take it in till you are familiar with the facts, the facts, the countless facts."

"You mean things like the humming-bird's powerful wings and the ostrich's powerful legs, and so forth?"

"No, no. That's what I don't mean. Didn't you notice my little parable about teaching the savage to understand the sun? You don't tell him to look at the sun. The longer he gazes at it, the blinder he will grow. No; you must tell him to look down at the sand and learn to put a pebble opposite each toe and say 'ten.' He must learn arithmetic before he can begin to hear your story about the big lamp that swings overhead. It's the same with us civilized people if we want to know about adaptations. We must begin by learning to count a hundred in the simple little facts of *variation*, and then to feel the temperature of the *struggle for existence*, and then peep through the telescope of the *geological record*, and then see some experiments with the gravity of *embryology*. It's a long process to understand how the sun is not designed to go around the earth.

"Go ahead for a while with your adaptations. They are facts, and you need to know them. But don't

injure your dazzled brain by thinking much about them at present. After you see a few samples of the gorgeous truths, turn back to your pebbles. It's the only way if you want to understand that the sun of adaptation does not revolve around the little globe of the human brain."

If we should interview all the zoologists and botanists in the country, we should receive the same kind of advice. Let's skim around the world and gather a few impressions of this blinding mystery.

High in the Andes Mountains, where the streams run violently among the boulders, lives a little thrush that is adapted for gaining a livelihood in the water. Its dense and fibrous feathers keep the body from being wet; it clings to stones at the bottom of the current and is able to swim swiftly under water. Yet it is otherwise very similar to our song-thrushes. Bats in the Mammoth Cave are able to fly, without ever brushing the walls, in the remote corridors where the darkness is complete. Some fishes and squirrels and lizards and squids are fitted with membranes that enable them to glide, almost to fly, through the air.

Turn where you will, in any corner of the earth, to look at any animal, and you will always see some beautiful or astonishing contrivance for seizing a living in the fierce competition of nature. How are the bees able to save precious time and more precious wax by making cells with six sides rather than four? Or what steering device enables them to fly so straight that they have made a "bee line" a proverb? Maeterlinck's essay on the adaptations of the bee makes the Arabian Nights seem flat. The firefly's apparatus is the envy and despair of every lighting corporation.

We could continue to flit thus from case to case through all the vast range of the vegetable and animal

kingdoms, and see in every specimen some new adaptation. From an elephant's trunk to the filament of a bacillus every detail of structure would furnish one more item for a record so extensive that no one person's life is long enough to read it. And even if we had time for examples from all parts of the tremendous catalogue, no such set of mere items would picture the principal truth. For when we look at one and another and the next, each seems like an independent exhibit, complete in itself, neatly stowed on its own quiet square foot of space in a dust-proof glass case. But in the swirling battle of life it is only a drop in the maelstrom, a part of the whole. No plant is adapted for itself alone; no animal is detached from the whirling struggle of the whole. Here are bacteria and flowers and ants that seem adapted for slavery to roots and bees and other ants. Elsewhere are poisons and claws that seem adapted only to destroy life. Everywhere in the maze there are plants like the mistletoe and animals like the Texas tick that suck the food prepared by other plants and animals. These are the parasites. In one sense all the higher animals are parasites upon plants, for they could not live without the food that green plants can form from the air and ground. It is estimated that half of all the known species of animals are adapted to be parasites and can not live in any other way. So adaptation is not all a matter of building up elaborate contrivances, but is often a case of giving up contrivances and becoming more simple and degraded.

Adaptation may not be a matter of forms. Often it is a set of impulses and instincts that direct animals to move to certain flowers or kinds of bark, or to take journeys of thousands of miles. Every one knows that shad and salmon luxuriate for most of their lives in the ocean and then are led by an irresistible impulse

to run up rivers for spawning. The somewhat similar romance of the seals has furnished material to Kipling. We all know these commonplaces. A more striking example of adaptation is the opposite kind of migration made by the eels.* These peculiar fish emerge from the ocean in their infancy as transparent, insignificant bits of ribbon two inches long; the females move up the streams and often journey overland; for years—sometimes ten or twenty—they continue to grow in size; then back they go to the salt water and swim southwest, swim for two years or even three, till they reach the deep water south of Bermuda; here they spawn; from here the young larvæ head northeast and toil back over the long, long weary three thousand miles, growing somewhat smaller during the migration; at length they reach the friendly fresh water where they can spend a happy decade, until they in turn are summoned to return to the cold depths, where they spawn and quickly die. These lengthy travels are an adaptation, and a very successful one; yet to our human way of thinking there is something cruel and creepy about it.

There is the same uncanniness about a whole host of migrations in nature. Certain fresh water clams give birth to young that attach themselves to the gills of a particular kind of fish—not of other kinds—where they live as parasites till they are ready to drop off and grow up into clams. If our delicate tastes are offended by this life-history, we may have one of the other sort—for there are all imaginable kinds in this jungle of adaptations. Read the pretty story of a fiercely spiked yucca, the Spanish bayonet, whose

*The general nature of the life-history of the eel was correctly guessed at sixty years ago, and evidence of deep-sea spawning was gathered twenty years ago; the announcement of the discovery of the Bermuda spawning region was first made by the Associated Press on July 22, 1922, in an account of Doctor Schmidt's seven-month expedition from the Copenhagen laboratory on the ship *Dana*.

stalk of beautiful blossoms is so much admired by tourists in the Southwest. This wealth of bloom would be impossible and the hardy plant would perish if it did not provide food for a certain delicate white moth —not any other moth—which brings it pollen from other yuccas. And the little moth could never live on the dreary plains if it was not fed by the sturdy yucca.

Such tales of ocean journeys and desert partnerships have a romantic quality that naturally excites us to "think" about the origin of the adaptations. We had better follow the advice of the bird man and not exercise our feeble logic. It is safer just to notice the facts.

Observe the colors of animals. In many cases the splotches and irregular lines of a butterfly's wings are a minute imitation of the leaves on which a butterfly perches. A sharp-eyed collector has often had the experience of seeing a specimen suddenly disappear from sight as if by magic when it lights; so perfectly do its folded wings resemble the surrounding foliage. The marking of some insects is like the appearance of bark or stem; the stripes of tigers and zebras cause them to blend into the landscape, so that they can better stalk their prey or escape an enemy. All through the animal kingdom are instances of different sorts of camouflage that render an animal inconspicuous: bears and rabbits and birds are white in the northern snow, while most birds and lizards are green in tropical forests. Sometimes the most remarkable of these "protective colorings" are the least spectacular. Sometimes they seem poorly contrived. If a speckled, dull-colored bird is protected by its markings, why should its breast be a shining white? An experiment showed why. An American artist*

*Abbott H. Thayer. His work was put into a book called *Concealing-Coloration in the Animal Kingdom* (1910), by Gerald H. Thayer; this volume is beautifully illustrated with ingenious photo-

painted two sets of dummy birds; to both he gave nature's colors on the back, and to one he gave nature's white breast; but to the other set he gave a dull-colored breast. Then he placed his two sets of dummies at a distance and observed them. Those that were painted nature's way, with the light breast, blended better with their surroundings and were harder to see. Yet even the artist had not expected this result, and had a hard time to reason out the peculiar problems of light and shade.

It is needless, even if we had space, to continue zigzag journeys from snow to tropics in order to pile up the evidence that throughout the whole world of life many animals are adapted by their colors for the struggle to exist. Such a lengthening of the list would be tiresome. But it will be worth while to notice two exceptions that prove the rule. (1) Some butterflies wear loud colors, seem to advertise themselves to hungry birds. This looks like the opposite of adaptation. But in such cases it will be found that the butterflies are protected in another way; they are for some reason extremely disagreeable to birds, which will not eat them. Hence they fly lazily about, for they are safer if they advertise themselves as an unpalatable kind. The wise birds know better than to catch them. (2) Some good-tasting butterflies are also conspicuous in their coloring, and also fly lazily about. Since they look nearly like the bad-tasting ones, and since they don't mind telling a lie about themselves, they are saved from the attacks of birds.

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graphs and colored plates, showing that "the most gorgeous costumes are, in their way, climaxes of obliterative coloration." Who would have thought that "the forest-tones of the peacock 'melt' him into the scene to a degree past all human analysis"? The authors show how Wallace's notions of coloration were partial and mistaken, but they out-Wallace him in proving the universality of these adaptations for protection. See also Theodore Roosevelt's *Revealing and Concealing Coloration in the Birds and Mammals, Bulletin of the American Museum of Natural History, 1911.*

And yet, for all their apparent resemblance, they belong to quite another family and are as different from the bad-tasting kind in structure and habits as pelicans are from eagles. What is more—incredible as the fact may seem—one species of good-tasting butterfly, within the limits of one country, has been found to imitate the appearance of three different kinds of bad-tasting ones.

At this point our uneasy powers of logic again throb for action, but the next set of facts shows the futility of logic. Among some species of good-tasting butterflies only the females are colored like the bad-tasting species; the poor males have been left most cruelly unprotected. It is only certain species of these good-tasting butterflies that resemble the bad-tasting ones; other species are left without any imitative coloring. In a common genus of the United States only one species is disguised; all the others have to live without protection.

Descriptions of all the freakish ins and outs of insect mimicry would fill a big book. Some beetles resemble other beetles, while some resemble bees. Wing-covers are extended, antennæ knobbed, and legs made hairy in the most comical ways, so that the normal structure can be detected only upon careful examination. A cricket has been found that—unlike all its relatives—has the outward appearance of an armored beetle, and another cricket wears the garb of the very wasp that preys upon it. Shall we argue that nature first designed the wasp and then mocked it by designing a disguise for its prey? We have all seen fierce-looking flies that masquerade as hornets and that have a body motion like a hornet. Is nature favoring these flies with her funny contrivance, or is she cruel to all the other flies? Some flies resemble bees and daringly invade hives to lay eggs; the larvæ that

hatch from these will eat up the young bees. Why should nature design such a crafty deceit of the bees, or why should she leave the poor things so witless as not to recognize the murderers? We could "think" that she played the same scurvy trick on some ants in Brazil, reasoning that when she made a little mantis in exact imitation of them and sent him among them to kill them, she was determined to punish them for wearing the clothes she had given them.

We have had enough examples of how sensible the advice of the bird man was. If more proof were needed, we could reprint pages of Wallace's chapter on Mimicry in his *Natural Selection*, telling how a caterpillar resembles a snake in color and pose—and many such oddities.

Adaptation is a bigger and more fascinating subject than any mere list of curiosities. It includes all those marvels of architecture that can be seen in whole groups of animals. We had best not describe the most astonishing of these, for they might give an impression of exaggeration. We may pass by such wonders as those of blood and digestion, which are largely beyond our ken, and speak of some bit of mere anatomy.

Look at a feather. We can see it is adapted for propelling a bird through the air in search of a living. Have you ever examined a feather or thought anything about it? Man has not made any material so light and stout and elastic as the thin horny quill. We say familiarly "as light as a feather," but we might better say "such a miracle as a feather." For its make-up is admirable beyond all description. From each side of the central shaft branch hundreds of miniature feathers, the barbs, each of which sends out its hundreds of branches, the barbules. These are airy plates, each of which is delicately and accurately

frayed into hooks on the forward edge, delicately and accurately grooved on the rear edge. Each barbule fits its hook neatly and firmly into the barbule in front of it and holds in its grooves the hooks of the barbule behind it. So precisely are these couplings made that the surface of a wing is as smooth as paper. One student of birds counted the parts of a crane's feather; there were over one thousand three hundred barbs on one side, each of which branched into six hundred barbules—eight hundred thousand adaptations on one side of "just a feather." And then the wonder has only begun. The different feathers on a bird are not all duplicates of one pattern; there are all lengths, all degrees of fineness from plume to down; there is a whole range of uses—for flight, for water-proofing, for warmth. When we have counted the parts of one feather and multiplied by the number of thousands of feathers on some heron that wades for shiners in a remote Adirondack lake, we begin to get a glimpse of what adaptation means in nature.

We often speak of these adjustments as "perfect." So they may seem. If we examine the sole of a fly's foot, noting the suckers and hairs that enable it to run about on a smooth ceiling, we are excusable for exclaiming, "A perfect contrivance!" But there are many exquisite structures at which we can only guess. We can, for example, see the remains of a certain microscopic plant which goes on propagating in quadrillions age after age and dropping its tiny shells to the bottom of the lake in which it lives; we can see that the markings on these shells—125,000 to the inch—are exactly equal and spaced at exactly equal distances from one another; they are so infinitesimally precise that they prove man's most skilfully made lenses to be clumsily inaccurate. Such perfection of structure could not have been an accident; yet we do

not know the use of it. We can only look with awe at these products of an unseen force of adaptation.

There are some features of plants which appear to serve no purpose whatever. In other cases—as when potatoes grow on stalks in the air—the machinery of the plant seems out of order. In many ways a long familiarity with plants causes a botanist to feel that adaptation is a means of "doing well enough" or is "a chance product of the play of forces"—and so is far from perfect.

An adaptation is often successful only for a time, in certain peculiar conditions. For instance, if a naturalist could have studied animals some millions of years ago, he might have called a "Thunder Lizard" perfect for its surroundings, because the bones a foot thick were such superb engineering for a cantilever skeleton that was sixty feet long. But when the climate changed, the Thunderer proved very, very imperfect, and his race died out. The record of the fossils is one long roll of creatures that were "admirable" and "perfect" adaptations for one way of life, but that perished because they were unable to live in competition with better forms. No doubt the old saber-tooth tiger was king of the beasts by virtue of the formidable weapons in his upper jaws, and no doubt the Irish elk was justly proud of his hundred-pound antlers, the hugest the world ever saw; but both adaptations were good for only one set of conditions; when the conditions changed, the adaptations brought their owners to destruction.

Many and many an adjustment that we see about us now is only partly successful. It appears that the bee is just well enough adapted to thrive, and no more: her instinct drives her to toil with such incessant vim that she dies after a few days of work at the height of the season; in many ways she is

stupid. The teeth of a beaver are certainly a successful adaptation in one way, but if they are not kept worn down by constant gnawing, they grow so long that they kill the beaver; that hardly seems a perfect arrangement. Flies are a good example of successful adaptation, yet they are so imperfect that they are subject to the ravages of a plague of fungus. Silkworms and elm trees have been threatened with extinction. We may properly speak of an eye as a most marvelous adjustment, may call it perfect, but in reality it is far below what an ideal instrument might be; one great student of optics said it was so inexact and imperfect that we might almost suppose nature was trying to keep us from knowing what the world really looks like. The way in which the leaves of plants can adjust their "breathing" to changes of temperature and moisture is a notable case of adaptation; yet it is so far from perfect that when a leaf opens its pores to let gases in and out, it may allow too much water to escape, and thus sometimes commits suicide. Adaptations are known to be imperfect, to succeed one time and fail another.

The botanist, as he studies the ways in which flowers are adjusted for bees, can not escape the feeling that all these beautiful and intricate devices are temporary, that flowers and bees have not always had this curious partnership. And the geologist says, "You are right. Only a little while ago, geologically speaking, there were no bees and no bright flowers in the world." So the botanist finds a double fascination in his study of the ways in which flowers are decked in colors and perfumed, their sweetmeats displayed, their barriers and passageways rigged up, their stamens and pistils set in order—always in such a manner that some bee or moth or humming-bird is tricked into carrying pollen. Every colored flower is

a fit subject for a long essay on adaptation: it must have pollen from some distant blossom, and must have its own pollen carried to another blossom; this conveying is done for some plants by the wind—and these have no colors or sweets; but plants which depend on insects lure them and pay them. Here is Darwin's description of how one orchid operates:

"This orchid has part of its lower lip hollowed out into a great bucket, into which drops of almost pure water continually fall from two secreting horns which stand above it; and when the bucket is half full, the water overflows by a spout on one side. The basal part of the lip stands over the bucket, and is itself hollowed out into a sort of chamber with two side entrances; within this chamber there are curious fleshy ridges. The most ingenious man, if he had not witnessed what takes place, could never have imagined what purposes all these parts serve. But Dr. Crüger saw crowds of large humble-bees visiting the gigantic flowers of this orchid, not in order to suck nectar, but to gnaw off the ridges within the chamber above the bucket; in doing this they frequently pushed each other into the bucket, and their wings being thus wetted, they could not fly away, but were compelled to crawl out through the passage formed by the spout or overflow. Dr. Crüger saw a 'continual procession' of bees thus crawling out of their involuntary bath. The passage is narrow, and is roofed over by the column, so that a bee, in forcing its way out, first rubs its back against the viscid stigma and then against the viscid glands of the pollen-masses. The pollen-masses are thus glued to the back of the bee which first happens to crawl out through the passage of a lately expanded flower and are thus carried away. When the bee, thus provided, flies to another flower, or to the same flower a second time, and is

Adaptation on the rocks of Nahant—from the barnacles at the top, which are able to live much of the time in the air, to the sponges at the bottom, which are fitted for being constantly covered by water.

A large model which shows to a slight extent how the malaria mosquito is adapted for its way of living. Even if this model were magnified a hundred times, we could see only dimly some of the larger adaptations.

pushed by its comrades into the bucket and then crawls out by the passage, the pollen-mass necessarily comes first into contact with the viscid stigma, and adheres to it, and the flower is fertilized."

From a picture of that sort we should like to go on through the gallery of adaptations, seeing how one plant spreads all its flowers and leaves in a space no larger than a pinhead; how leaves and roots, when they first emerge from the seed, do not grow in the wrong direction; how plants blossom late or early, and thus avoid some competition; how the tips of roots are highly organized mechanisms for pushing through stiff soil and forcing water, with substances in solution, up to the stem; how tumble-weeds bowl over the prairies and scatter their seeds, and cockleburs hook themselves to cattle by the most delicate barbs, and milkweed pods send out their seeds in the finest silky parachute; how sap is pumped up three hundred feet in tree-trunks by a process that no physicist has yet explained. But there is not space in this volume to do more than hint at the endless variety of ways in which plants are adjusted to live.

A set of pictures of ingenious mechanisms is all very well for entertainment, but is apt to blind us to the far more marvelous facts of adaptation that are to be seen in the anatomy of any plant. If we, like a child, are satisfied with shouting, "Oh, see the pretty seed sail!" we shall forget the deeper wonders of the structure of one of those gossamer threads that float the seed along. Every slightest shred of such material passes understanding.

Here at our feet is a bunch of clover. As you look at it indifferently, you are, in comparison, like some giant a million miles tall who is looking at our earth. If his eyes were no sharper than ours, he could not detect Chicago or the height of the Andes. So, if we

wish to see anything of a clover leaf, we must make ourselves small. We must reduce ourselves to the dimensions of a medium-sized microbe—to the height, say, of one-ten-thousandth of an inch, while we retain the vision and the mental powers of a man.* Permit yourself to be thus minimized while we take an excursion for a few paragraphs into this clover leaf that nods in the breeze—just an ordinary, matter-of-fact, humdrum leaf that is carrying on its existence by the use of certain commonplace adjustments to soil and light. Shrink yourself gradually, and thus avoid too great a shock. First you are two inches in height—four times as tall as the width of the leaf, which now looms before you a spiny, big-ribbed affair, glowing with life. Then you are reduced to a tenth of an inch; you cling to the edge of the leaf, which seems thirty feet broad, and you feel a vertigo as a breath of air swings you through an arc of twenty feet. Become ten times smaller still; the leaf is a hundred yards broad, and the little fuzzy hairs appear as spiny trees fifteen feet high that glisten against the background of billowy green. If you submit to another similar reduction, the opposite edge of the leaf will be more than half a mile away, lost to view beyond the swell of the surface. One last reduction, and here we are—two microbic pygmies at the edge of a leaf nearly six miles wide. We find ourselves perched on a ridge that is as rugged and jagged as an arm of a volcanic mountain. Indeed we are on a more perilous footing than those tourists in the Yellowstone Park who motor over a rocky knife-edge that slopes steeply down three

*I have tried to carry out Ganong's hints: "The student can see photosynthesis proceeding as clearly in imagination as he could with the physical eye were he sufficiently small to wander at will through the intercellular passages, and view the operations through the crystalline walls of the cells"; and "the ordinary stoma [pore], when open, presents to a molecule of water an exit as great as a passage seven miles wide appears to a man."

thousand feet on either side; for our leaf is in its fleshiest part less than a thousand feet thick.

Beneath us we feel the throb of the mighty protoplasmic engines; we have glimpses of great streams coursing beneath the shining water-proof surface of the top, which undulates for two and a half miles to the cañon that is over the midrib. All this plateau is covered by a forest of the white spines that rise like giant masts of crystal fifteen hundred feet above the network of blackish veins.

Before we venture into the terrifying interior of this monstrous place, be assured that we are not playing with a fantasia. Small as we have made ourselves, we are not nearly small enough to penetrate the last secrets of a leaf. Our vision is still far too coarse to see even the most puffed-out molecule of starch or sugar, which would be to our gross microbic eyes only one-two-hundred-fiftieth of an inch in diameter. No, small as we are, we have descended only to those limits that a microscope can reach, and are still like great blinking monsters before the ultimate adaptations.

We are altogether too large to enter through the upper side of the leaf; no space there would admit a finger. We peer along the under side. About a hundred yards away is a hole that looks promising. Fortunately there is a thousand-foot spine, rooted beyond the opening and growing across it, close along the under surface, that offers us a rough bridge. We scramble along on this huge sparkling log, below the under surface of the leaf, till we are beneath the mouth of a cave. At first we are almost blown off by a blast of oxygen that is rushing out, and then are almost sucked in by a whirling current of air. At the edge of these currents we find a place where we may swing ourselves by our hands up to an oval aper-

ture that is heaving in an alarming manner. We can feel the surge of sap in the bulging guard-cells, which sway the wall of the cavernous mouth to and fro; they might quickly swell across the opening and crush us. Luckily at just this moment they are slowly drawing apart.

We venture between them when the opening becomes five feet wide. We find ourselves at the bottom of a funnel whose wall rises steep and slippery forty feet above us. Up this we clamber. Here at last is quiet and security, for we are in an open space some fifty feet wide and a hundred high, whose sides are composed of a dozen or more irregular blocks. Imagine some houses, with elastic walls, wedged tightly but not accurately together to enclose a great chamber, and you will have an idea of the surroundings that close us in. The walls of these houses are six inches thick, but so nearly transparent that we can make out fairly well what lies behind them—green globes and disks, ten feet or more in diameter, that are suspended in a sort of thin syrup, and that are slightly in motion. The "houses" are the cells. The green globes are the machines that manufacture sugar—and sugar-making is the chief business of a leaf. In the course of a summer it will produce enough sweet food to form a layer half a mile deep over its whole surface.

If we wish to explore, the way lies open above. We had best take our bearings, so that we shall not get lost in the galleries that ramify among the big cells. Our forty-foot climb up into this chamber was through the under surface of the leaf; we are now in its soft interior. Above us lies the thickness of the leaf—perhaps six hundred feet—which is packed nearly full of the house-like blocks, through whose walls we have been looking. These are the green cells; half a dozen layers of them are between us and the

top surface of the leaf; all around us they stretch, out to the very edges—a million or more of them. We are going to climb around through the air passages that twist and wind in every direction among the cells, and we must keep good track of our directions, or we shall never find our way back.

Through the air-passages we poke our way between the pulsing walls of the cells and mount toward the upper side of the leaf. The cells become more narrow, more close-packed, more green, until, when we have struggled upward four hundred feet, we come to the base of a close array of them that are much longer, wedged tight together, like so many flexible boxes, reaching to the upper surface. They deserve their name of the "palisade" cells. At one point we can squeeze another hundred feet through an air-channel, but here it ends, and we must stop.

Familiarity with these more active upper cells shows somewhat of their inside. The sugar-making disks, smaller and flatter here, float in a liquid. But the liquid is only the lining of the cell. All the interior is filled tight with sap, which holds the syrup against the wall.

We never tire of watching this syrup, viewing it as if through the glass of an aquarium. It is in constant motion, sometimes swirling by a mile* a minute, sometimes busied with little whirlpools; now it is of the faintest green color, and now yellowish; here it is a thin, translucent jelly, and there is filled with fibers and rods, globes and crystals. It is protoplasm. It is life. Whatever other wonders we see in a leaf are explainable to some degree by a chemist, but man has hardly spoken the first syllable that shall help to interpret protoplasm. When we have begun to under-

*Actually four miles—if a mile is reckoned as nine hundred times our microbic height.

stand it, we shall have begun to understand life—not before. It is as different from mere sugar as a man is from a stone. If you grant a biologist just one cell full of this protoplasm, he can imagine that from it came all the classes of life; without it he can not account for the beginning of life; all inorganic matter, be it ever so complex, is on one side of a great gulf, and protoplasm is on the other side.

What a purblind, witless thing is man when he encounters a leaf!

As we continue to explore, we are overpowered with the complexities that surround us, of which we can gain hardly any knowledge. Here is a strange cell that contains, as if it were a show-case in a museum, a glittering, spiked crystal five feet in diameter. We are bewildered by the currents all about us: air circulating everywhere, water pumped through tubes, sugar carried out for transportation to the roots that need the food, sugar transformed to starch and back again to sugar.

And all these operations are simple compared with the other functions of a leaf. Not all of man's factories and laboratories can equal the refinement of the varied processes that go on every minute here. There are special cells to produce the water-proofing for the outside of the top; others make cellulose and build the walls of veins with it; there are the guard cells that regulate the intake and outgo at the pores. A leaf compounds the most delicately adjusted kinds of intricate carbohydrates and proteins, of oils and fats and coloring-matters and alkaloids and digestive fluids and acids, and many products that are quite beyond detection.

Suppose that the human mind could partly grasp the possibility of assembling all these activities in a soft plate half an inch wide and one-hundredth of an

inch thick; the mind would only have begun its journey of understanding. What regulates and directs the whole organization? Where is the "nerve center" that tells ten thousand pores to open five per cent. wider because the temperature has changed? Where is the mechanism that controls the turning of leaves for a better spread to the sun? Whence issue all the uncountable thousands of orders every hour to the hundreds of thousands of cells, telling them when to work and when to desist? What engineer so directs the currents that in every least vein the sugar is floated toward the stem and water is propelled in the opposite direction? We weary of a mere rehearsal of a mere part of these orders for work.

Our excursion is over. Now we may enlarge ourselves to our normal size and be again the blind and massive monsters who can see nothing in a leaf. We look down at the hall of wonders where we spent such an adventurous hour—at a mere clover leaf bobbing in the wind. Somehow our minds are no longer interested in "thinking" about adaptations. For all this assemblage of intricate powers is but a fragment at the outer edge of a tenfold more marvelous assemblage—a whole plant, whose leaves and roots work as one body for producing flowers that can summon the bees to aid them in producing seeds. And a seed is the supernal wonder, for within its narrow case are enclosed all the adaptations of a mature plant, every detail of every kind of roots and sap-ducts and stems and sweet scent and future seeds. Here within a seed is a universe which appals the mind as much as the farthest reach of the starry spaces, and which is farther from our comprehension. Here centers the whole of life. All adaptations are but means to this end—that the power to live shall be passed from an individual to its offspring. If we would know the

little that the scientists can learn about the secret, we must lay aside all our gross and savage superstitions as to how nature might work if she were a mortal. We must realize that nature is not revolving around our human ways of thought to be a convenient servant to us, but that her secret is the remote force about which our petty minds swing in their unknown void.

Probably we can never grasp the secret, any more than an astronomer expects ever to fly to the sun. But we can observe it to some extent. We can see a little way into the material facts of life, and can learn how great is the distance from the heedless disregard of a leaf to the central fact of adaptation.

CHAPTER VI

THE STRUGGLE FOR EXISTENCE

This chapter is the first of four steps in describing evolution. It is a description of the fundamental fact—never understood a century ago—that the life of every plant and animal is a struggle in a fierce competition for a chance to exist and propagate. If nature had caused all her creatures to live by a policy of "give the weak ones a chance," there never would have been any development of such adaptations as were described in the previous chapter.

Early in every man's life there comes a time when he hears the story of the blacksmith who offered to shoe a farmer's horse for some grains of wheat—thus: one grain for the first nail, two for the second, four for the third, and so on. Of course the farmer was pleased with such a price. The driving of the fifth nail cost him only sixteen grains, and the total wages for putting on the first shoe were only two hundred fifty-five grains. The farmer kept tally: two hundred fifty-six grains for the ninth nail, five hundred twelve for the tenth, one thousand twenty-four for the eleventh. He was amused, and the more so because his wheat was small; it took five hundred of the grains to fill a cubic inch, and a million of them to make a bushel. The last nail of the second shoe cost him not much over a quart. He lighted his pipe and smoked contentedly, reflecting that he was paying hardly anything for the labor and nothing for the material.

The trouble began while the third shoe was going on; the twentieth nail cost 524,288 grains—half a bushel; the twenty-first a bushel, the twenty-second two bushels, the twenty-third more than four bushels; the total for the third shoe amounted to sixteen bushels. The thirty-first nail cost over a thousand bushels; the total price for the job was four thousand two hundred fifty-six bushels.

When we tell this story to children, we are amused at their skepticism and pleased with our effort to show them the difference between adding two and multiplying by two. We do not realize that we need the lesson for ourselves when we consider successive generations of animals. The rate of increase is not found by *adding* to their number each time, but by multiplying. Most animals tend to increase by a factor larger than two, and it does not require a long stretch of years to include thirty-two generations. Even a seasoned mathematician is rather startled when he figures the number of descendants that one pair may produce in no long while.

The largest and most slow-breeding kind can furnish amazement if we grant them a few centuries. Suppose that the average pair of elephants produces only four children that live to have grandchildren, and suppose that there are only three generations in each century, and suppose that the parents die as soon as they have brought up their last child. Under these conditions one pair will have sixteen great-grandchildren in the world after a century, one hundred twenty-eight descendants after two centuries, and one thousand twenty-four after three centuries. The rate of increase may seem as insignificant as it did to the guileless farmer. But in five hundred years there will be sixty-six thousand descendants; in six hundred years there will be over half a million, and after

another century over four million. Now the numbers roll up. In the thirty-second generation of descendants there will be eight billion five hundred million—that is, five times the human population of the globe. After seven more centuries of increase there would not be standing room for the elephants if they were packed closely on every acre of land surface from pole to pole. Does seventeen centuries seem a long while? It is not the thousandth part of the centuries during which elephants have been breeding on our earth.

There is no trick in this reckoning; the figures do not lie; they give a conservative estimate of the way elephants actually would have increased if they had had a chance. We know as a matter of history that a few horses, left by the Spanish conquerors of Mexico to run wild, must have increased on our western plains for a century or more at a rate that doubled their numbers in each generation.

As soon as we deal with smaller and more short-lived animals, the normal rate of increase is prodigious. In 1860 a few rabbits were carefully conveyed to Australia and tenderly nourished there with the hope that a few of them might be able to live and propagate. Never was a hope more abundantly fulfilled. So rapidly did they multiply that within twenty years they were a pest; rabbit-drives had to be organized, and such heaps of the animals were slaughtered that it was difficult to dispose of the carcasses. A fence of wire mesh was run clear across the continent in order to head off this prairie-fire of life.

Any animal that bears several young in one litter and breeds several times a year can soon make a counting-machine weary. In two years of the World War the rats multiplied enormously along the battle line—amid all the destruction of artillery and poison gas, in spite of the utmost efforts to hold them in

check. Against the unremitting warfare of man, rats have always increased wherever there is food. One estimate of their fecundity in England is that, even if ninety-five per cent. of them died without breeding, they could quadruple their numbers in a year. If they had food and room, and were not opposed, their skins could make a carpet for the earth in a few decades.

Some similar computation would be true of any animal that is normally adapted to hold its own in the world. It is fitted to increase in swarms, and ever multiplying swarms; and whenever it has opportunity, it infallibly lives up to the predictions about its fertility, actually does propagate in overwhelming numbers. The English sparrow was brought to our shores in 1851 and promptly set to work producing every season several large broods. Within twenty years it had become more numerous than any native bird. The point of this story is not that a certain sparrow is an undesirable citizen, but that any bird in a favorable environment will unfailingly produce astounding numbers in a few years. A very moderate estimate will show that a pair of blackbirds could easily become ten millions in ten years, and that many ordinary birds could have two billions of descendants in fifteen years—would unquestionably have that many in favorable surroundings. When the Ohio Valley was being settled, the pigeons used to be seen in such numbers that we gasp as we read the naturalist Wilson's account of what he once saw in Kentucky. "They were flying with great steadiness and rapidity, at a height beyond gunshot, in several deep strata. From right to left, as far as the eye could reach, the breadth of this vast procession extended, seeming everywhere equally crowded. It was then half past one. About four o'clock in the afternoon the living torrent above my head seemed as numerous and extensive as ever."

Wilson reckoned that in this one "torrent" there were two billion pigeons; and this was "only one of several aggregates known to exist in various parts of the United States." Yet these pigeons hatched *only two eggs at a time.*

Every form of plant or animal life has some similar ability to multiply its numbers. Until we hear that statement repeated, and repeatedly emphasized with examples, we can not have any conception of the prolific power of all life. For even observant people have very little opportunity to realize the abounding vitality of all animate nature. And most of us are not observant. I, for example, hardly see one rat a year, hardly know an English sparrow by sight, am much impressed by the way my trees and shrubs tend to die. I always see, year after year, the same numbers of crows or buzzards or woodchucks. What do I know about the power of life to multiply?

And yet even my dull eyes have seen a few cases of the swarming of animals. I have seen the sky darkened at midday by the grasshoppers that were preparing to descend on Nebraska corn-fields. They came, as they come in Africa, from some distant breeding-grounds in hordes so vast and destructive and swift that they stagger the imagination. About the middle of the last century a sudden pest of caterpillars appeared in the forests of Prussia; so numerous were they that the noise of their droppings was like the rustle of rain.

Most Americans have seen potato-beetles, and some have speculated on their numbers. The history of these humble beetles is more extraordinary than the tale of Tartar tribes. For unnumbered centuries they had lived a hard obscure life in Colorado, feeding meagerly on a plant that belongs to the genus of tobacco and potato. About 1850 one of them sniffed

something delicious in the breeze. She flew in that direction and lighted on a cultivated potato plant that was in a new settler's garden. The power of fertility increased with this new food supply, and across the fields of the juicy helpless leaves it took its devastating course. Within a few years the potato-beetles became an advancing army; they spread north and south, deploying on the plains with a front one thousand five hundred miles wide and rolling eastward at an average speed of two miles a day during the two months of summer when they could breed. At the close of the Civil War the army had progressed across Illinois; in 1872 it was in eastern Pennsylvania; and three years later was reported in Vermont. If there had been food, and no enemy to spray with poisons, these beetles would by this time have been numerous enough to pave the earth with a layer of their wing-covers.

There is nothing exceptional about such increase of numbers. It is an entirely normal case, one that would be duplicated in a few decades or centuries by any ordinary animal that found favoring conditions. It has been surpassed by the more recent increase of the cotton-boll weevil. Where this came from is disputed, but in 1894 it "appeared" in Texas, and ten years later the head of our Entomological Bureau declared: "The Mexican Cotton-Boll Weevil has the unique record of developing in less than twenty years from a most obscure species to undoubtedly one of the most important economically in the world." He estimates that during the five years after 1917 it destroyed upward of a billion and a half dollars' worth of property. He has not set any staff of clerks to figuring on the rate of multiplication of the little beetle. He has been too busy trying to fight down the increase of another boll weevil in Texas, a pink one

from India, that had the best of a four-year battle with the forces of the Bureau and multiplied enormously against all odds. In June, 1922, the press reports told us: "State commissioners of agriculture estimate that the boll weevils are about five times as numerous as they have been before at this period of the season."

Every book on evolution gives illustrations of the way each species is fitted to multiply boundlessly. One of them* says: "If every egg of the herring should develop to an adult fish, it would not be long before the Atlantic Ocean would fail to contain them." Another† cites the case of a species of white ants: "A female, after it is full-grown, does nothing but lie in a cell and lay eggs, producing eighty thousand eggs a day steadily for several months." A third‡ contributes estimates of this sort: "A single fern-leaf of a common species produces about fourteen million spores; a tape-worm produces hardly less than one hundred million eggs."

It will be safe to repeat the statement that these cases are not exceptional; they represent the normal provision of many plants and animals for propagating themselves. They are so commonplace that every author may set forth fresh ones. We must not lengthen out our list unduly, but should indicate briefly the inconceivable fecundity of several other classes of life to whose existence we seldom give a thought. When I try to find earth-worms for bait, I seem to prove that they are a very restricted genus; but it has been shown that in rich soil there is an average of fifty thousand of them to the acre. There they work, unknown to me, patiently grinding up stomachfuls of

*W. B. Scott, *The Theory of Evolution.*

†Jordan and Kellogg, *Evolution and Animal Life.*

‡Weismann, *The Evolution Theory.*

leaves and dirt for a little nourishment, and then casting out the residue. "In many parts of England," Darwin tells us, "a weight of more than ten tons of dry earth annually passes through their bodies, and is brought to the surface in their castings, *on each acre of land.*" Huxley reminds us that in the body of a living fly there may be "countless millions" of individual fungus plants. When passengers on an ocean steamer see night after night the phosphorescence of the water, every sparklet of light in the steamer's wake for the thousands of miles is made by an individual animalcule. In all parts of the tropical oceans are little coral animals that fasten themselves to rocks, like sea-anemones, and there make for themselves a limy skeleton which remains after their death; so tremendous is their power of reproduction that they have built the Great Barrier Reef of Australia, one thousand two hundred miles long and in many places one thousand eight hundred feet thick. In stagnant warm water we find animalcules whose grotesque forms can be seen readily under a small magnifying-glass. One species has been found to breed at the rate of six hundred generations a year. It has been estimated that if every individual should breed in normal numbers for five years and if none died, the volume of the three thousand generations would be "approximately equal to 10^{1000} times the volume of the earth."* Remind yourself that 10^{1000} means ten with nine hundred ninety-nine ciphers after it, and that such a sphere would include more space than astronomers have measured.

It is easy enough to see why the animalcule does not continue its rate of increase—there is not space for it in the universe. It is clear why no fish has packed the ocean full and why elephants are not

*L. L. Woodruff's *Foundations of Biology*, page 375.

standing five hundred thick on every acre of land. The reproduction of every species—even if it were the only one in the world—is limited by the supply of food. And since there are half a million species of animals, each of which would like to fill the earth and would be quite able to do so, there must be a severe pressure upon every species by all the other species that are tending to swell in numbers and to occupy the same territory. Such a pressure must cause intense rivalry; it must restrict, must strongly check, the increase of each individual. This check upon the increase of numbers causes the "Struggle for Existence."

As soon as we hear that ominous phrase, we naturally begin to think of warfare, of bloody design. Indeed the literature of evolution is dotted with hints of this sort, and of late years the story-writers have given us many pictures of the world of nature as a battle-ground where all feet are swift to shed blood, a cruel place where venom and claw make way with enemies, where "nature is red of tooth and fang," where life is a "gruesome cockpit." This horrible notion* is so generally held that it has been used to justify human warfare. The German Bernhardi actually argued as crudely as this: "Wherever we look in nature, we find that war is a fundamental law of evolution. This great verity, which has been recognized in past ages, has been convincingly demonstrated in modern times by Charles Darwin."

*William J. Long in his *Mother Nature* has done good service by denouncing this notion as "an appalling and degrading superstition" (though his own notion is not one that many naturalists endorse). The ideas of "cruelty" and "terror" are not to be found in Darwin. Long's book is only an amplifying of the description that Darwin gives as a summary at the close of Chapter III of the *Origin of Species*: "When we reflect on this struggle, we may console ourselves with the full belief that the war of nature is not incessant, that no fear is felt, that death is generally prompt, and that the vigorous, the healthy, and the happy survive and multiply."

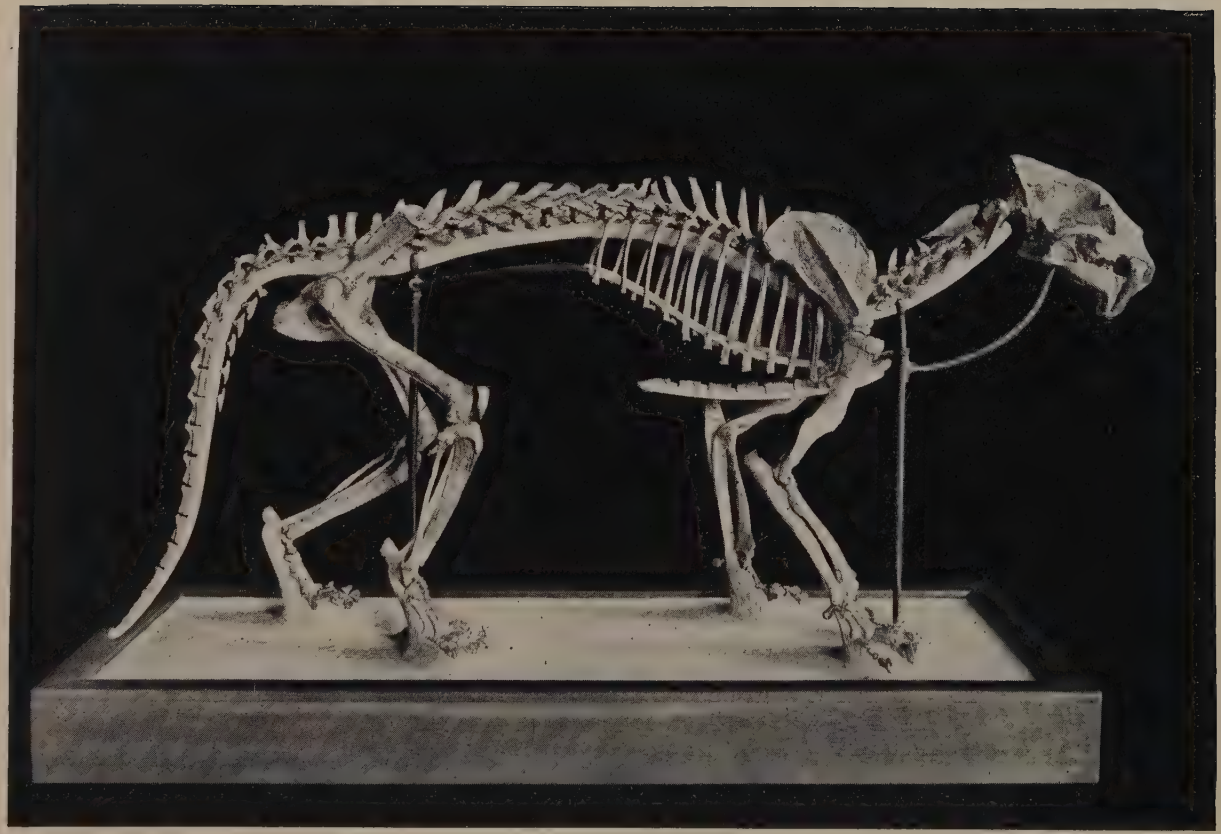
In the main all such ideas are false. To compare the struggle of nature with human warfare is absurd. Because we human beings are cruel to one another, because *we* plunge into ruthless wholesale killing, because *we* have tortured and enslaved and exterminated one another in our struggles for *domination,* we can not assume that the struggle for existence is similar. Only a gorilla has a right to such an argument. Before any one can have a true view of evolution, he must thoroughly purge his mind of this common and deep-seated error. Before we go on in this chapter to picture the struggle for existence as it is, we must take time to see what is not.

It is not what our sentimental human minds would suppose. If we conceive it as cruel, as fierce-minded, as warlike, we are making the old mistake of having the great sun of nature revolve around our little mental sphere. Nature is not bitter with human hate. Nor, on the other hand, is nature sweet with human sentimentality. Nature is as different from a man as the starry heavens are from their reflection in a pool. "Nature" is simply a name for The Way Things Are. In this great scheme of things we can not detect any plotting of altruism nor any exercise of cruelty, neither sympathy nor jealousy. To our poor senses nature may seem like a loving mother, or like a stern inexorable stepmother; but the beauty and the harshness alike are flimsy imaginings; they are not nature.

The struggle for existence does not invite men to go to war nor certify that might makes right nor discourage charity. It is not hideous, but partakes of the beauty of all truth. It contains no cruelty, unless all facts are cruel.

In the whole long history of false reasoning there is no funnier chapter than the record of how man has

The struggle for existence in a one-inch radius on a rock of the seashore, magnified to show the diversity of life. Not much of a "gruesome cockpit" about this, though the competition is of the severest kind.



No doubt the saber-tooth tiger was king of the beasts by virtue of the weapons in his upper jaw; but when conditions changed, his adaptation brought him to destruction. Page 66.

sentimentalized the struggle for existence. He has shuddered at the fierceness of the tiger while digesting the beefsteak of a slaughtered cow. He has written poetry about "the pious robin"; yet for every kill of a tiger a robin will slay his hundreds. The only relentless and unreasonable slaughterer on earth is man. No wonder that man, who exterminates moose and bison while he tolerates the marriage of idiots, is quite unable to comprehend the wisdom and purity of the struggle for existence that is decreed by nature.

The struggle for existence is a contest in which there is no motive of cruelty, no lust for power over others, no desire to do harm to another creature. It is an effort by every creature to do his best, his utmost, to live and have young. Every force of his being is animated by these two elemental instincts: (1) he must live according to the law that nature has planted in him, and (2) he must obey the primal commandment to be fruitful. Every act in the natural struggle for existence is entirely innocent and wholesome.

In another way the struggle is unlike what we might assume. It is not a universal combat in which every creature's weapons are turned against other creatures. In a great variety of ways animals and plants are useful to each other, confer benefits on others in the course of seeking their own welfare—as when birds remove caterpillars from leaves. Success in the struggle often comes from avoiding competition—as when the sage-brush grows on the desert where other plants can not live.

In another and more important way the struggle differs from what we have so far dwelt on. It is to a large extent not a set of duels between individuals; the contest is often impersonal, unfelt, unsuspected. Perhaps an illustration from human life will be useful

here: if an actor or an author pleases the public, his work may be highly paid for, and the income of some other actors or authors be reduced. Stevenson says that a successful author—who may be a shrinking, affectionate person—stabs other authors with his pen as surely as if he used a dagger. So impersonal and unsuspected may the struggle for existence be at times in human affairs. Much more is it true that the unreasoning lives of a large part of the animal kingdom may be passed without any consciousness of rivalry, in peaceful success. Success need not depend on the ability to kill. All through the millions of years of the geologic ages the armored fighters have perished; to-day one of the most prolific animals is the least offensive—the rabbit. The rats and beetles have not conquered in the strife by slaughter. Some of the most successful animals are those that organize a society, like the ants and bees, in whose colonies there is no individualism, but only a ceaseless, unstinted labor for the whole group.

But the struggle, for all kinds alike, is none the less fierce and unremitting because it is indirect and unknown. It is pitiless. If a communistic society of bees can not find nectar in competition with other societies, it will fail to leave offspring as surely as the lonely pair of eagles that fail to strike enough victims in their wide domain of sixty square miles. When any kind of organism can not produce enough seed, or suck enough water from the ground, or resist a plague of fungus, or withstand a change of climate, it dies. There is no more tragedy about this for the individual than there is about the most successful life, for every individual, weak or strong, must die. The only difference is that, in the long run, the weak leave few offspring; the earth is peopled by those who leave most offspring. "Reproduce or perish" is the eter-

nal necessity. In this struggle to propagate, the mushroom feeds upon decaying matter, the condor wheels its lonely flight above the mountains, the fish feels its sightless way in caves and ocean depths, the mosquito swarms beyond the arctic circle, the snow-plant spreads its abundant red upon the ice-fields of cold heights, the beaver builds his dam. High and low, everywhere under the whole heaven, in every cranny of space, with every imaginable adaptation, the urge of life compels every individual to seek out a living and have young.

Though we can learn very little about the adjustments in nature, we can guess at them to some extent by what we see when man disturbs any balance. As soon as the dry valleys of California were set to orchards about fifty years ago, the cottony cushion scale multiplied upon them at such a rate that destruction was in sight. The orchards were rescued* by studying nature's adjustments in Australia, the home of the scale. It was found that there the scale was kept in bounds by ladybird beetles; some of these were imported, bred and turned into the orchards; they promptly and completely played their expected part in the struggle for orchards. The cantaloupes were saved from a pest by a similar army of ladybirds brought by the bushel from the high Sierras. Man's best, and often the only, way of coping with the multitudes of nature is to employ the troops of nature, as in fighting the gipsy moth, the Hessian fly and the grain aphis. We are in a perpetual contest with the hordes of life that swarm against our interests.

Some such gross examples are about all that man can learn of the interplay of forces that work in the struggle for existence. If we look at any landscape,

**Mustering Nature's Mercenaries*, by Elizabeth A. Ward, in the *Forum* for October, 1915.

we see that all forms of life are fitted into a mosaic where each can thrive to a certain extent, thus far and no farther. Each is, in the ordinary course of the seasons, checked from dominating over others. Grass and spruce trees and violets and robins exist in abundance, and now one and now another may fluctuate somewhat in its numbers; but as the decades pass, the balance only swings to and fro about a center. Each plant and animal is severely restrained by the whole competition. Year after year we look upon the same peaceful assemblage, hear the same songs, see the same bright blossoms, exclaim with the same satisfaction at the restful peace of it all.

But there is no peace. In any landscape each leaf and beak and fin is tirelessly at work to keep up its numbers. Every plant bears seeds in prodigious quantity; every animal's body is a factory of countless eggs or sperms. With all the power of every mother's being there is effort to rear young. Every pair of individuals is doing its best to leave descendants that would spread over the whole region. With what result? Only this: that next year, and ten years hence, and fifty, and a hundred, there will probably be the same number of descendants. All this ceaseless power is somehow held in check by the competition of powers. Of all the seeds that are formed by a plant with such lavish extravagance only a few sprout. "There is a British starfish which produces at least two hundred millions of eggs, *and yet it is not what one would call a common animal.*"* There is something fearsome about such tremendous possibilities that accomplish no more than just to keep the numbers of this starfish from decreasing. Many of the lower animals hatch a thousand eggs to insure one offspring. And only a small fraction of the young can grow up.

*J. A. Thomson, *The System of Animate Nature.*

The rearing of all the offspring with such intense devotion has only one result, that when the years have passed and the parents have died, there are two other members of the species to take their places.

Here is a fact to which the ordinary citizen never gives a thought. The pretty scene that he surveys from a porch or a canoe is a cemetery for the young that never mature. We need not weep their fate, but we observe the fact. This is the struggle for existence.

CHAPTER VII

VARIATION

The previous chapters have been descriptions of life as a naturalist sees it—bird's-eye views of what plants and animals are like. In this chapter and the next two we shall spend some of the time studying the inside of eggs.* At a point where the course changes in this way we had best look back a minute to see what ground we have covered.

The first four chapters, displaying the myriad forms and the tangled web of life, were a preparation for Adaptations. Until we realize something of the intricacies of life, we can not see much of a mystery about their adjustments. When we have had a good look at Adaptations and have wondered how they were made, we are ready for the explanation. The explanation is in four steps: The Struggle for Existence, Variation, Heredity, Natural Selection. The first of these (in Chapter VI) was a view of the way every form of life is doing its best to multiply, though it can seldom do more than hold its numbers even. Looking at this struggle was a survey of the facts as a naturalist sees them.

*A biologist uses "egg" to mean the female germ of either an animal or a plant. After the fertilized egg of a plant has reached a certain stage of its development as an embryo, the development ceases; and this dormant embryo is what we know as a seed. It would be convenient, and perhaps not misleading, to speak of eggs and seeds as synonymous terms in this elementary book, but a biologist could not tolerate such a use of words. "Egg" in this chapter means any fertilized germ-cell of any plant or animal.

But Variation is different. Here we quit tramping in the open with Darwin and Wallace; we are in the laboratory, looking through the microscope at revelations that have been made since Darwin died.

Variation,* as used in this chapter, means simply the fact that young are never precisely like their parents. We know that no child ever exactly resembled its father and that no tree was ever an accurate reproduction of its mother. We do not need to be told that among all the races of men in all time there were never two exact duplicates, and we can believe that no two flowers are ever so similar that a microscope would not show differences between them. We are as familiar with variations as we are with a clover leaf; but we have never been inside of them, never have realized what it means in nature's architecture *to vary a pattern.*

The extremes of such variation are called monstrosities. The Siamese Twins were two men joined to each other by a thick tube of cartilage, through which their vital organs were so closely connected that no surgeon dared cut them apart. They were very unlike their parents. The Bohemian Twins† were a pair of women who had only one spine between them. When they died, the courts had to decide whether the twins were one person or two persons. This two-in-one body bore no resemblance to its parents or ancestors. Peppino Magro, twenty-two inches tall when fully grown, and Kazanloff, one hundred and eleven inches tall, varied from their parents in stature. They were born with some peculiarity of a little gland which

*Note for any critical reader: This chapter has little to say about the distinction between somatic modifications, recombinations of genes, and germinal mutations. These technical questions are outlined in Chapters XXII, XXIII and XXIV (Section III).

†The Blazek sisters, who died in Chicago, March, 1922.

directed their growth abnormally. A baby that is born without arms, or with a jaw-bone growing in its body, or with a full set of teeth, or with a hairy nose and forehead, or with a tail, shows a decided variation from normal parents.

Animal monsters are constantly being exhibited and reported: Siamese twins among fishes have been the special study of one French zoologist. Calves are born with an extra pair of little legs hanging from the shoulder, or they have peculiar heads and are called "dog-headed" or "human-headed." A cat has been born with only two legs, on which she learned to walk; and a lamb has lived without any legs. A stag may have one of its antlers growing downward.

Among plants there is no end to the monstrosities that are frequently seen. Ears of corn are double or distorted, or have unnaturally arranged kernels. A little peach sprouts from the cleft of a large one, or a kind of second orange may appear at the base of an orange. A bean, which normally sprouts with very large leaves, at the base of which are little insignificant scales, may show gigantic scales and no leaves. If we ask what caused these peculiar variations, we can think of only one answer: something abnormal occurred in the development of the egg. What does that mean? What are we talking about when we carelessly pronounce the words "change in an egg"? If I may judge others by myself, we are thinking of nothing at all. People spend intellectual lives, studying psychology or art or history, with no more curiosity about an egg than if it were a drop of water that may change into steam or ice according to the temperature. Yet a germ-cell is a compound of unexampled marvels, more intricate than the whole galaxy of suns and nebulas, containing in its deep recesses secrets which lie far beyond the reach of the most skilful user of a

microscope. A germ-cell is life. We shall never know much about it until we have penetrated all the rest of the universe.

But something has been learned—enough to show in a general way the course of the evolution of life upon the earth. It is very recent knowledge, hardly seventy-five years old. Within those years all the understanding of the nature of plants and animals has been revised by learning about "cells." Thirty years ago the study of these was largely devoted to the masses of them in tissues (called "histology"); nowadays the college courses attack the cell directly; everything is cells, cells, cells. An old-fashioned person may grow weary of this chorus that perpetually wells from all our laboratories; but as soon as he discovers the reason for it he must sympathize. The study of the cell has given us the greatest revelation of how nature works in molding life.

Recall that time when we stood within a clover leaf gazing through the crystalline walls of a cell, behind which surged the streams of protoplasm. We watched the varying gray mass of viscous liquid, within which we could faintly see strands of fiber forming some sort of open mesh. It was a piece of life, complicated and specialized for its own duties. Its core was water and sap; around its walls, in the protoplasm, were the green sugar-making globes; the protoplasm flowed from point to point, directing all the details of a sugar factory. It could repair its own walls, summon water and gas, send out oxygen, ship its products out through connecting veinlets. It had a skill that lies beyond understanding. In other cells this protoplasm knew how to transform food and energy; in others it made the roofing material; in others it concocted oils or fats or colors. It transmitted orders to the workers in the pores and hairs and veins. Hence it is more than

a substance that a chemist can analyze; it is beyond analysis. It is not a certain kind of material, any more than jelly-fish and lions could be called the same kind of animal material. "Protoplasm" is only a convenient name for our blindness when we look into cells. Since we can not detect the differences, we give the name "protoplasm" to the living matter that we see.

If we had observed the protoplasm of the clover-leaf cell as clearly as the highest-power microscope does, and had had a guide to tell us where to look, we could have distinguished in it a little body, no larger than one of the sugar-making globes, the "nucleus." In this small globule is contained the guiding power of the whole cell, as if it were the office of a factory. It is this nucleus which directs the birth of a new cell.

Are you at all startled by hearing about "the birth"? This cell that we are looking at—this subtle aggregate of powers—could no more happen into existence than a camel or a whale could, for it is an organized unit of life. If I see a hawk flying overhead, I know that he was once an egg and was born. It is just as obvious that the cell was born. It must have grown out of a cell, which had grown out of a previous cell, which had grown from a previous cell. There can not have been any gap in the series of descents from the time when life began on the earth. Every cell, in every leaf and muscle and brain, is the offspring of some previous cell.

The origin of a cell in a clover leaf can not be any hit-or-miss process; a new cell can not "just branch off somehow." Even a beet-sugar factory that man makes—a clumsy pile of apparatus for doing the simplest sort of crude work—has to be designed by an architect with elaborate fulness. There must be complete blue-paper plans, an engineer's care to have founda-

tions solid, a builder's minute pains to have walls kept plumb and courses of brick level, expert work to make steel girders exact, expert manufacture of vats and engines, high technical skill to furnish spectroscopes and chemical reagents. If so lumbering an institution as a man-made factory requires all this provision, much more will the creating of so intricate an organism as a plant cell. Of all the secret processes in a cell not the least jot of a small item of one can be left unprovided for.

The specifications for a future cell lie in the nucleus. When this receives the impulse to reproduce, its mechanism is set to work, and it operates its hundreds of minute parts with an accuracy that is awesome to think of. So small is the space within the nucleus and so dim are the outlines of operations that no scientist could ever have charted the scene by himself. But after a generation of work the experts are now able to give us some picture of the steps of a birth.

They tell us that in the course of half an hour or more the following program is carried out: First the nucleus spreads out to occupy a larger portion of the cell. Several loops appear in the liquid; they grow shorter and thicker and become straight; they then arrange themselves in the center of the cell, as if they were so many bits of a small thread, placed end to end in a plane. Each of them splits down its length into two equal parts, as if a fine knife had been driven through the bits of thread and had divided them all at one blow. Thus the original tangle of loops has been separated in an orderly manner into two equal sets of straight pieces. The two sets now draw apart, moving away from the equator of the cell toward opposite poles. Meanwhile the whole cell has been preparing to divide: a groove has appeared on

its outside, as if made by a string that had been drawn tight around it in the same plane where the little bodies split within the nucleus. The groove grows deeper and deeper, till the cell is split in two. The result is two small cells, each composed of half of every detail of the previous cell, each with a complete equipment of cell life. These grow quickly to full size and are now prepared to reproduce in the same way as often as they have orders to do so.

That brief sketch of cell birth may give a wrong impression by its comparison with "bits of a thread." Of course the real processes, if our senses were fine enough to see them, would appear as a set of countless adjustments made rapidly with supreme nicety. And perhaps the crude sketch has made a reader forget the size of the space that encloses all the operations. The whole cell is so small that it may not take up more than a millionth part of one leaf. Of the minute space in this cell the nucleus fills only a fraction. Even within the nucleus all the complexities of a future organism are arranged for in one small part of the space—that is, in the bodies that split apart. The mind can not begin to comprehend such close packing of forces; it quits exclaiming about "marvels" or "unspeakable mysteries" because any words of wonder fall so far short of what we feel.

The best we can do is to accept the bare fact that in those infinitesimal loops at the limit of microscopic vision is packed the complete outfitting for the whole life of a daughter cell. These are called "chromosomes," a word that means "color bodies."* Every one of the cells that make up flesh or wood or animalcules arose in this way by means of chromosomes. They can create a new cell that inherits all

*So named because they were first made visible by coloring them with a stain.

the peculiarities of the old one, and hence they are called "the carriers of heredity."

There are endless varieties of cells. The live bark of a tree is built of several kinds, each with its own individual sort of protoplasm to keep up its activities. Bone and mahogany are made by protoplasm that builds hard walls for its cells, and then dies. In the brain are cells where protoplasm keeps records of sensations and manages switchboards for sending messages to other cells. A nerve-cell is a long, slender fiber. In a cubic inch of normal human blood there may be seventy billion cells, fitted to do special chemical work or to rush as soldiers against invading forces. The small red ones are generated in endless billions by mother cells that live in the bones. There are cells that lead separate lives as individual animals —like an amœba, for example, which is a single cell that opens up any part of itself for food.

Cells are of all sorts, of all degrees of complexity; but all alike originate by the mechanism of chromosomes.

Before we go on to describe the variations that originate in chromosomes, it may be well to speak of a common misconception, one which used to mystify me. I refer to the use in older books of the word "simple" to apply to germ-cells. "Simple" means only that the cell is "single," that there is only one of it. The human eye is called "simple" in comparison with the multiple eye of a fly. In this sense we might say that Paris is a "simple" city and George Washington a "simple" man—because the city and the general are not compound. A "simple" cell may be, potentially, as intricate as an animal.

Keep that statement in mind when you hear that every egg is a cell. A grain of clover pollen is a cell. Inside of this is a nucleus, within which are the chro-

mosomes. They are what count.* They carry all the specifications for a whole new plant, for all the types of cells that are to form roots and ducts and stems and leaves and hairs and blossoms and future seeds. In them are, potentially, all the structures of the next generation, complete to every least item, such as making each hair taper to an end that is somewhat pointed, but rather blunt and irregular. The chromosomes are faithful agents, powerless to disobey, for carrying out these specifications. They can not construct grass or huckleberries; they can not construct another kind of clover; they can only reproduce a plant like the one from which they came.

This holds true for every egg of any kind of plant or animal. In every egg there are some chromosomes within a nucleus, and their development is all determined in advance: they are compelled to build their new life on the pattern of the parents. No earthly power can reach inside the chromosomes and make a new pattern for them to follow. Nor is there any way of so altering a parent that its reproducing cells will create a different species of body. However much you may mutilate a clover plant or a fowl, if you allow the egg-making organs to work at all, they will produce the only type of egg that they are fitted to produce. They must make the identical kind of chromosomes that their parents made and that their offspring will make. The business of chromosomes is to reproduce by the given pattern.

Yet, in spite of this, their machinery is never precisely perfect. *It does sometimes vary the pattern.* That is *variation.*

We know next to nothing about the reasons why

*A cytologist would find this statement over-simplified, for there is no doubt that the other contents of the cell have their part in reproduction. See E. B. Wilson's *The Cell,* (1925) Chapter IX.

chromosomes vary from their normal operations, but can only notice that they do vary. Their inexactness is not surprising. Indeed the wonder is that in such intricate work as theirs they ever can follow the model as closely as they do. We should naturally expect that there would sometimes be slips or failures in the machinery.

Variations are sometimes spectacular, giving rise to a new variety or species. In 1791, on a Massachusetts farm, was born a ram whose legs were so short and body so long that he was nicknamed the "otter"; he was valuable because he could not jump fences, and he became the founder of a new breed of sheep called the "ancon." Forty years later the same sort of thing happened on a farm in France. A ram was born with a large head, long neck and legs, covered with smooth silky wool; he was the forefather of a new and valuable kind of sheep. Such sudden creations, or "sports," are decided alterations that chromosomes make in the pattern they are supposed to follow—"happy mistakes" we might call them. Such a mistake certainly brought joy to a Kansas farmer in 1889, who one day found that a young calf in his herd of Hereford cattle had no horns; it founded the race of "polled Herefords."

These great variations are celebrated because they were so useful to man and were as romantic as the discovery of a new diamond mine. Yet they show no more peculiar shifts in chromosomes than many cases that are only curious freaks of passing interest. Man has never taken advantage of the forgetfulness of a chromosome that did not put a tail on a colt.

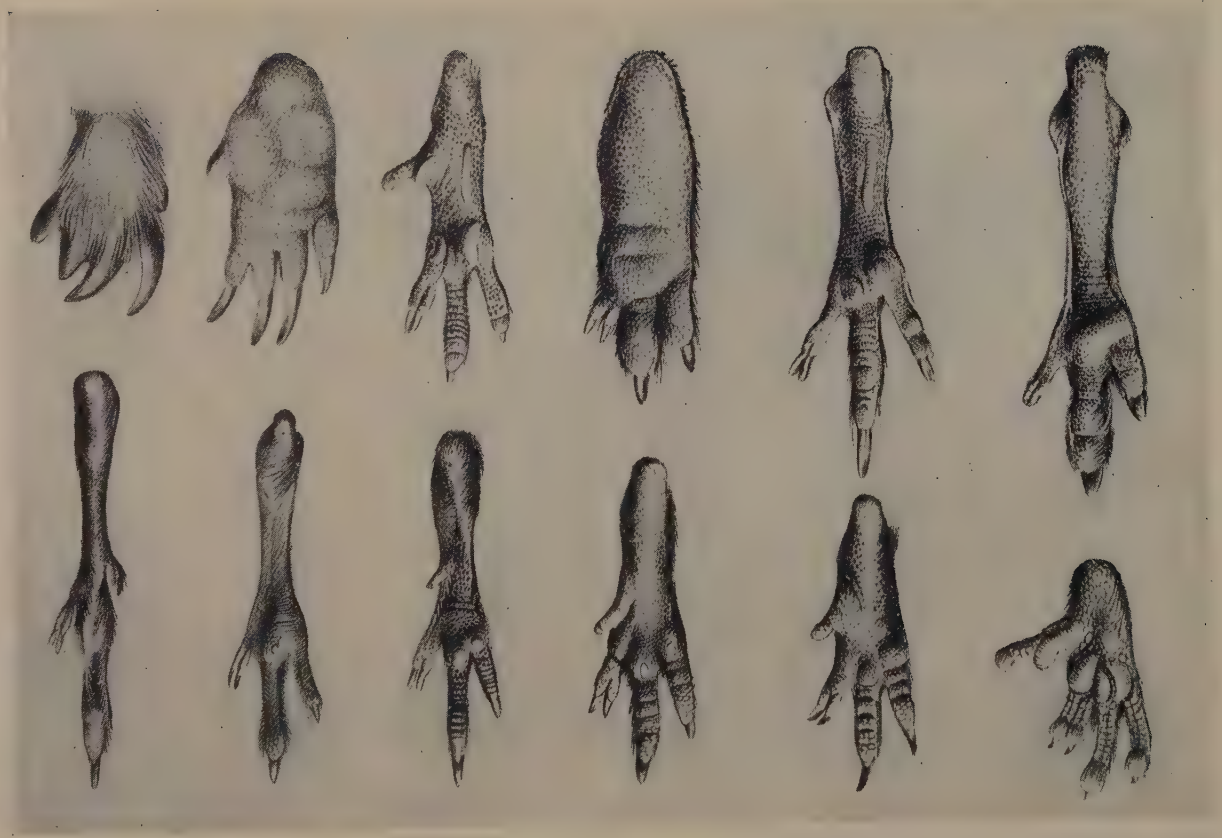
There was once a set of chromosomes in an orange that did not put in any seed-making apparatus, and that ornamented the base of their work with a queer whirl. An orange-grower noticed this sport and liked

it; since then the "navel" orange has been on all our fruit-stands. A dozen years ago Professor Cockerell* saw in Colorado a native sunflower, a wild plant, that was red. Here was something new in the world, a sport produced by a chromosome that had transferred the coloring matter from the disk, where it belonged, to the flowers at the edge of the disk. So rarely is such a slip made that, with one possible exception, no other case was ever reported. Darwin exclaims thus about a sporting plum: "When we reflect on the millions of buds which many trees have produced before some one bud has varied, we are lost in wonder as to what the precise cause of each variation can be." Today we may still be "lost in wonder" if we try to imagine just the motions that a chromosome would make in building a new variety of plum, for the motions and materials are beyond our range of imagination; but we can now understand in a general way that in the mechanism of chromosomes there may once in a while be a shift of gears and that such alterations may be fortunate.

One of the most useful plants for man is wheat. Its chromosomes are restless and variant; one Frenchman claimed that he had cultivated over three hundred varieties. Though most of these sports show only slight differences, occasionally there is a large and decided one. About twenty years ago in Canada two different varieties were mated; the chromosomes were so stimulated to mix up and recombine their elements that a hundred variations resulted, one of which—it appeared on only a single stalk—proved to be a hardier plant with better bread-making qualities than North America had known before. It was named "Marquis." A century ago this fact of the sudden sporting of wheat was known; a famous Scotch grow-

*T. D. A. Cockerell, *Zoology.*

No two caribous ever had antlers that were exactly alike: there is perpetual variation in this part of the body, as in every part of all animals and plants.



Australia is Nature's museum, where she has preserved the marsupials that became extinct (except for the opossum) everywhere else in the world. How they have evolved in the most diverse ways is indicated by their many kinds of feet.

er* testified that he had never seen grain which had been improved "by cultivation," but only "by selecting the new varieties which nature occasionally produces, as if inviting the husbandman to stretch forth his hand and cultivate them." In 1819 he "observed quite accidentally a single plant of a deeper green and more heavily headed out"; this he cultivated, and it became one of the best kinds for the region where Walter Scott lived.

In 1923 "a single branch of red apples was sold by Lewis Mood of Ferrell, New Jersey, to a nursery firm for five thousand dollars." The year before "fifty thousand dollars was paid for a single strawberry plant by the R. M. Kellogg Company of Three Rivers, Michigan, to its grower, Harlow Rockhill, of Conrad, Iowa."†

So far as we know, all improvements in domesticated plants and animals came about in sudden variations, sometimes by a long leap and sometimes by a great number of very short steps; they appeared as unearned gifts from the chromosomes. We have records of a golden-colored grape that sprouted from a black variety in England, of "a multitude of varieties that sprang from one seed" in a French vineyard, and of new hothouse varieties that are produced "almost every year." Each kind of apple was originally a solitary sport, a unique product, made by changeful chromosomes.‡ No new kind of peach was ever attained by effort, but always by discovering a novelty hanging on a tree. If an agricultural experiment station should try for a century to train the seeds of a

*Shirreff, of whom Darwin says, "A higher authority can not be given."

†Associated Press reports.

‡Such changes may not be an appearance of a character that was never in the heredity; they may be only "recombinations" of ancestral characters, in such a way that the new combinations can be inherited. See Chapter XXIV, Section III.

potato, it would fail; its only hope is to be on the lookout for what the seeds have happened to bring forth.

Chromosomes tend to make some of their variations repeatedly. Every one knows that most clover leaves grow in clusters of three, but that in any field there are several clusters of four and may be clusters of five or more. Men have always observed that some pigs are born with a solid hoof instead of the usual two toes; pigs may occasionally have a third toe, or a pair of bristly tassels under the throat. Most colored animals occasionally have white young, and these albinos are often less hardy than the parents, being less able to withstand heat or poisons or parasites. In any flock of peacocks there may suddenly appear a bird of smaller size with black shoulders, as if the chromosomes of this animal were prone to make, every so often, this particular kind of variation. The shell of some species of snails regularly grows in the direction in which the hands of a clock move, but occasionally specimens grow in the opposite direction. Human chromosomes give a small percentage of us two-jointed fingers or freakish powers of multiplying mentally.

If only one double thumb or one four-leaf clover had ever been seen, we might suppose that chromosomes had strange independent powers of their own, that they were like people who enjoy playing a joke or inventing a novelty. In the same way a South Sea Islander who had seen only one motor-boat in his life would suppose that the engine had mental powers of its own and was a kind of harnessed demon. But any civilized man—though he may speak of an engine as "acting badly" or may swear at the "perversity of inanimate objects"—knows that an engine must follow the set laws of mechanics. Every biologist knows that chromosomes are absolutely bound by the fixed

laws of physiology; however "comical" or "bungling" their work appears, they are just as passive organs as a heart or a blossom is.

And even when they produce a novelty their work is, more often than we think, of a routine sort, like putting color in the unusual place or putting on a fourth leaf. The celebrated Dutch botanist de Vries warns us that when we see in a bed of white flowers one blossom with a bluish tint this unexpected blossom may not be a real sport. He knew how often the irregularities occur regularly. In his search for real sports he found a varying primrose that promised well; he observed its variations for sixteen years, and in 1903 published a big book on the subject. He believed that his primrose had sported into seven distinct new species and into many others that were less decided. He described "the very first moment of the appearance of two of the new stout species" and said that "they seemed to have inherited the capacity of producing in their turn new mutants." *Mutant* was his word for a new species that suddenly sprang into existence; on this idea of "mutation" he built a theory that has been the talk of the learned world for twenty years. Yet those "new species" whose birth he celebrated have also sprung into existence on Long Island, and have also sprung into existence in England, and perhaps have been born regularly at intervals for centuries, like so many five-leaf clovers. Possibly de Vries fell into the same trap that he warned us amateurs against. Thus we see that variation is an extremely complicated matter, about which there is still much to learn.

You and I seldom take notice of differences in nature between the parent and the young. Even the experts sometimes fail to find them: the goose, though domesticated for thousands of years, has shown hard-

ly any changes. But almost always the close observer finds the variations, as this quotation illustrates: "Mr. Bates, after examining above a hundred of the big beetles, thought that he had at last discovered a species in which the horns did not vary; further research proved the contrary." If a specialist can make such a wrong supposition, surely the rest of us need to see the universal truth displayed in a series of quotations from men who know by long study that chromosomes can never be trusted to be absolutely exact: "I have seen it gravely remarked that it was most fortunate that the strawberry began to vary just when gardeners began to attend to this plant; the truth no doubt is that it had always varied." Of course it was the truth; three hundred years ago some shrewd gardener "availed himself of the inherent power of variation possessed by the plant." All beans may look alike, even to the most sharp-eyed grower, but "after two severe frosts only three of the three hundred ninety scarlet-runners remained, not even the tips of their leaves being browned; it was impossible to behold these three plants, with their blackened dead brethren all around, and not see at a glance that they differed widely in constitutional power of resisting frost." "The gold-fish, from being reared in small vessels and from being carefully attended to by the Chinese, has yielded many races." "Where flowers are grown by the acre for seed, scarcely a season passes without some new kinds being raised." Naturalists tell us just as emphatically that *wild* plants and animals show the same tendencies as the domestic. The wild orange plants in the jungles of India have the characters of the bitter variety, "but occasionally wild oranges occur with sweet fruit." "The chestnut trees may possibly survive the present blight, because there may be here and there one that contains a secre-

tion which will kill the attacking fungus; there are such trees in Asia, whence the blight came." "Our common forest trees are very variable." "It is probable that all insects occasionally show some abnormality of wing venation." "The description of new mutant types in almost every plant and animal that has been carefully examined indicates the very general occurrence of definite mutations." The prevailing fact of variation is put thus emphatically by Wallace: "We find no evidence of greater variations in domesticated animals than in wild ones."

Any one may become an investigator for himself if he is curious about variations in nature. Gather a dozen potato-beetles and scrutinize the brown stripes that mark their wing-covers. The first one that I saw this spring had between two of his stripes a heavy cross-bar that would have earned him a nickname if he had gone to school. Though his scientific name (*decemlineata*) means "ten-lined," he often fails to show ten lines on his back. The veins on the wings in any species of fly are usually so true to a pattern that they can be relied on as a mark for classifying; but careful examination of a few hundred wings will show that they are not precisely similar.

Darwin, an exceptionally keen-eyed naturalist, often marveled at the skill with which breeders of animals detected slight variations that were invisible to him: "In the great majority of cases a new character is at first faintly pronounced, and then the full difficulty of selection is experienced. . . . The finest powers of discrimination and a sound judgment must be exercised. . . . I have been astonished when celebrated breeders have shown me their animals, which have appeared all alike, and have assigned their reasons for matching this and that individual. . . . The best flock-masters do not trust to their own judg-

ment or that of their shepherds, but employ persons called 'sheep-classifiers.' When the lambs are weaned, each in his turn is placed upon a table, that his wool and form may be minutely observed. . . . Those alone who have associated with pigeon fanciers can be thoroughly aware of their accurate powers of discrimination acquired by long practice. I have known a fancier deliberately study his birds day after day. . . . Sir John Sebright used to spend two or three days in examining, consulting, and disputing with a friend which were the best of five or six birds. . . . Wherever silk is produced, the greatest care is bestowed on selecting the cocoons from which the moths for breeding are to be reared. Near Shanghai the inhabitants of two small districts have the privilege of raising eggs for the whole surrounding country, and that they may give up their whole time to this business, they are interdicted by law from producing silk."

We know that only persons with inborn talent, trained by long experience, are fitted to judge at shows of dogs or poultry or cattle. These judges are experts in variation, and to them no two animals ever appear identical. Exact reproduction is never to be found. In the patterns made by chromosomes there is perpetual *variation.*

CHAPTER VIII

HEREDITY

Every reader of this book knows that the sun does not move around the earth. Also he knows that the moon does move around the earth. These two heavenly bodies, which appear to be of the same size and to move in the same way through the same path over our head, are as different in size as a grain of sand and a baseball, as different in motion as the second hand and the hour hand of a watch. The moon does what it seems to do; the sun is deceptive.

There are two principles in evolution which seem like counterparts of each other—Variation and Heredity. Heredity is like the moon—it is near to our common knowledge and it is what it seems to be. Variation is the sun of the system—much larger than it appears, more remote from our understanding, and deceptive in its motion. All evolution revolves around Variation. All evolution is determined by the fact that chromosomes never reproduce exactly. As you read this chapter and the next one, keep your mind on Variation as the center of the whole theory. College teachers who have hammered away at this subject for twenty years testify that the minds of students are always forgetting that the prime cause is Variation. Many a college graduate, fresh from his course in biology, will falter and go wrong in trying to explain the subject because he forgets to start with Variation. That is the reason why Variation was described so

emphatically in the previous chapter. It was put before Heredity and Natural Selection. Fasten your mind to *the variations made by chromosomes.* A useful slogan among students is "keep your eye on the chromosomes."

It is small wonder that we all tend to put the explanation wrong-end-to. The whole world always had it hind-side-foremost until 1859, and in every-day life we invert the truth as naturally as we say that "the sun rises."

Consider a pair of examples. The first is the color of the negro. I always used to suppose that Adam was a white man, that some of his white descendants migrated to Africa, that the first generation of them was tanned by the tropical sun, that their children therefore *inherited* a somewhat browner skin, and that the grandchildren were somewhat browner still, until finally the race became so thoroughly brown that it was black. I never asked myself, "How could sunburn be inherited?" When a man has learned to keep his eye on chromosomes, he can see that no amount of tanning will alter the skin-making part of that mechanism. The second example is bow legs. It is natural to take it for granted that about a thousand years ago Spanish men became bowlegged from riding horse-back, and that in the course of thirty generations of knights and vaqueros each child *inherited* the bow legs that his father had acquired by clasping a horse for twenty years. We never inquire how this exercise of leg muscles could enter the germ-cell, then penetrate the nucleus, and then set up alterations in the infinitely delicate and complicated mechanism. The notion is absurd to any one who will keep his eye on chromosomes.

Less than a century ago the whole world assumed that acquired tan and muscle-development could be

inherited. The most learned scientists believed that if a man enlarged his forearm by labor or trained his fingers to write a good hand, his son would in consequence have a bigger arm or write the same kind of hand. All the great naturalists of Europe thought that if a giraffe continually stretched her neck for food, the offspring would inherit some of the strength and stretching ability that she gained by this exercise.

This is a very common idea, on which we have all been brought up. We naturally take it for granted that if we train two generations of pointers the third generation of pups will inherit more ability to stand motionless, that if we keep the feathers plucked from ten generations of hens the eleventh brood of chicks will have scantier plumage. This common and natural idea used to be accepted as the theory that "acquired characteristics can be inherited." A "characteristic" means any item of the bodily or mental make-up, such as white hair, big biceps, thick fingers, weak lungs, keen sense of smell. It is the word that Darwin used, and is the natural one, but nowadays the scientists use instead the shorter word *character*. "Acquired" means produced in the body during its lifetime. Thus if a parrot's tongue is slit or if a lion learns to live on vegetables or if a blacksmith's arm is increased in size by wielding a hammer, the changes thus made in their bodies are said to be "acquired characters." The theory taught that if we cut off the tails of a male and a female cat, their offspring might, as a result of the amputations, be born without tails. Even so late as 1887 there were exhibited at a Naturalists' Congress in Germany some kittens that were said to have been born with only stumps of tails because the mother had lost her tail by an accident—that is, she had "acquired the character of taillessness." And

even the most famous promoter* of the cell theory took the exhibition seriously! Scientists gravely listened to stories of how a dueling scar was inherited and how a man's frozen thumb caused misshapen thumbs in his grandchildren.

All through the nineteenth century the scholars discussed the question, "Can scars be inherited?" The greatest German philosopher argued before Darwin was born that they could not be, and in Darwin's old age the greatest English philosopher was still arguing that they could be. The debate might have gone on till doomsday if a common-sense biologist named Weismann had not cut off the tails of a pair of mice to see whether their young were born without tails. Instead of "thinking" how heredity might work, Weismann, like Columbus, sailed into the facts. The little mice were born with full-length tails, which were promptly amputated. The whole litter of this second generation was carefully brought up and allowed to breed together. All of the third generation were born with normal tails, which were at once amputated. Their young of the fourth generation still failed to acquire taillessness, and their caudal equipment was cut off. There was no inheritance in the fifth or the sixth or the seventh generation; there was no slightest evidence that acquired characters can be inherited. The experiment was continued for twenty-two generations, and the last litter of mice had tails just as long and perfect as the first. The 1,592† bodies of the twenty-two generations were preserved in alcohol and are to-day a monument that marks a turning-point in our ideas about heredity.

The second chapter of the mouse-tail story is as significant as the first. When Weismann published

*Virchow. See Weismann, *The Evolution Theory*, II, 64.
†Herbert E. Walter, *Genetics*.

his result, the scientists did not credit his report as truth simply because it was to be found in print. Before they believed it they repeated the experiment to see that it was correct. Reverend professors in several European laboratories devoted themselves to amputating tails of many successive generations of mice and rats. Not one of them found any proof that acquired taillessness could be inherited. Since that day no one has found any such proof, and now the scientific world has abandoned as unproved the idea that any sort of bodily mutilation can be inherited.

This change of opinion is not founded on logic. So far as logic goes, we could reason that the amputation of a left leg would give the body a shock, that this shock might be transmitted to a germ-cell, and might there kill that part of a chromosome that was commissioned to build the left leg of a child. Nature *might* have made the reproductive machinery in that way. But she *did* not. No credible case has ever been found of a bodily injury being transmitted to offspring.

Yet some cats are born without tails. Why? Because the chromosomes in the single cell where their life began had no tail-making apparatus. The young of Manx cats and wild bobcats have no tails because those races are tailless; none of their kittens can have a tail unless some disorderly chromosome varies so much as to form one. On the other hand, every maltese cat or tiger must inherit one unless some chromosome,* by a freakish variation, fails to provide it. All depends on chromosomes. If for a century breeders should cut off the tails of bull pups or clip the ears of fox-hound pups, the heredity would not be affected; the chromosomes continue, undiscouraged, to make the same long tails and ears. Although aristo-

*Of course monstrosities may sometimes be caused by faulty development in later stages of the embryo.

cratic Chinese women have deformed their feet by binding them in every generation for two thousand years, the child that is born to-day has normal feet, formed according to the pattern that chromosomes faithfully follow.

That is the business of the germ-cell—to reproduce the ancient model. Though there is always some slight variation, and may occasionally be a big one, yet the descent always tends to persist unchanged.

If the chromosomes that formed a certain man unkindly gave him a deformed joint at the base of his thumb, they may pass on the bad trick to the next generation of chromosomes, which may follow the new model, and so a son may inherit the deformity. But if the man slashes the thumb with an ax, the wound produces no effect on the chromosomes of his germ-cells, and the big scar can not be inherited.

You may plant big potatoes in poor soil and dig small ones; then for a dozen more seasons you may plant the descendants there and find them always small. But plant the next generation in good soil; you will have the same large ones with which you started. If a quick-growing young pine tree is transplanted to the top of a rocky mountain, it will become small and wizened, leaning away from the prevailing wind, unable to grow an inch a year in height; and the seeds that sprout from its cones in that neighborhood will form dwarfed and distorted trees. But the chromosomes have not been made correspondingly lopsided or shriveled. If you plant one of the seeds in good lowland soil, it will spring into straight and prosperous growth. The "environment" on a mountain is unfavorable and will alter every generation of trees that grow there.

Suppose that you captured an owl, a flesh-eating bird, and fed it on grain, as a famous English phy-

sician once did; if you could keep it alive on that diet, its stomach might be somewhat altered after a couple of years. But when the owl laid an egg, the chromosomes would be the same unchanged mechanism, and would proceed to create exactly the sort of stomach with which the parent was born. The character of grain-eating—like the dwarfing of the pine tree—is acquired by the body, and a change of that sort has never been known to be inherited.

That word "acquired" is often misleading. We usually think of some ambitious or aggressive act when we hear it, such as "acquiring a lot of money, acquiring a big reputation." But there is nothing aggressive in the technical meaning. A plant or animal does not make any effort to get hold of a character. By some accident or disease, by some action of climate or food or mental stimulus, a change is forced upon it by an outside influence. And this change is always in the body-cells—in the muscles or bones or nerves or membranes.

Within all this aggregation of body-cells lie the germ-cells, very distinct and leading a very separate existence. They were set apart when the egg began to develop. Near the beginning of every person's life the germ-cells for forming the next generation were set aside, in a secure place, where they could lie dormant until the body had grown to maturity and had set them in action. From that early moment of embryo life on to the end the germ-cells are beyond the reach of any ordinary outside influence.* No specific character can be forced upon them.

Nowadays it is known that some bacteria are so small as to be able to reach the germ-cells and affect

*The paragraph does not mean that germ-cells can not be affected in any way through the body; it means what the last sentence says—that no corresponding, heritable variation can be induced in the germ-cells by an outside influence.

them. We know, for instance, that the spores of a silkworm parasite penetrate eggs that are still within the caterpillar's body, develop with the embryo, and so afflict the young with the disease. The germ of syphilis is so small that it may be transmitted in the same way. Yet even such cases are not inheritance, because they are influences from outside the germ-making apparatus. Beyond that moment when the original cell has divided, the individual has begun its separate life, and any change is an acquired character. This is not a matter of definition or stickling for a point; it is a fundamental distinction. Any one who cares to keep his eyes on the chromosomes will see it.

In no ordinary case can disease or alcoholism or any form of debility acquired during an individual's lifetime be specifically inherited by its offspring. And any men who build theories on a few apparent exceptions must nowadays speak in different terms from those which were used thirty years ago. No modern scientist claims more than this: that a profound change in the body-cells might be communicated to the germ-cells, and so might stimulate or interfere with them. Thus an outside influence might throw the chromosomes into confusion and cause defective work. Or if a chromosome is carrying two patterns, the first of which would normally be suppressed, an outside influence might be a disturbance that could cause that first one to develop, or it might act as a kind of trigger that would throw into gear an old pattern which had lain dormant in the chromosomes for hundreds of generations. But no outside influence can remodel the machinery or add a new part. No outside influence can produce a *corresponding* effect in the germ-cell, any more than the carbon on a spark-plug can make a carbonic engine. Darwin expressed the effect of an outside influence thus: "The nature

Two examples of Nature's experiments in bone-making. The hero-shrew, above, has a spine that looks like lace-work; the pigmy armadillo has a dirt-rammer at the base of its spine.

An experiment in bone-making at the top of the head of Triceratops, some sixty million years ago. For an account of this horned dinosaur, and of the development of the extinct monsters shown in the next six pages of pictures, see the entertaining, illustrated, low-priced, reliable book by F. A. Lucas, *Animals of the Past*, to be bought at the American Museum.

of it is perhaps of no more importance than the nature of a spark in determining the nature of the flames." Darwin was always skeptical about the inheritance of acquired characters, and did not base his theory on it,* though he is often accused of doing so.

The great body of evidence coming from the laboratories to-day shows how independent germ-cells are of the body-cells, what a detached life they lead, and how they work by a routine process. Any one who could for a few minutes look with his own eyes at the "mechanism of heredity" that Professor Morgan of Columbia has demonstrated by experiments and studied under his microscope would never again be hazy about acquired characters. This man—and dozens of other recent investigators—has taken the guesswork out of chromosomes. What Darwin did not live to see, what Weismann saw dimly and speculated about, he now pictures for us in books† that all may read. In nuclei not one-ten-thousandth of an inch in diameter he has seen the operations of the beginning of a new life in a cell. He has seen chromosomes intertwine, exchange parts with each other, and move asunder; he has seen them solitary and in equal pairs and in unequal pairs; has seen them split apart; has watched their actions vary with temperature and observed their regularity. He has seen the chromosome that determines whether the new animal shall be male or female.

All this is wonderful enough, but he has gone much farther. He has proved with painstaking care that certain parts of certain chromosomes have their particular jobs. (These parts are called "genes.") He has been able to predict from the way chromosomes

*See Chapter XXIV, Section V, for quotations.

†*The Mechanism of Mendelian Heredity* and *The Physical Basis of Heredity.*

join with each other whether the egg will develop into an insect with shield-shaped wings or forked wings, with white eyes or red eyes. He has found that sometimes the work of many genes is necessary to make some one slight character. After breeding millions of little fruit-flies through hundreds of generations and tabulating the results, he and other investigators were able to make a map of the main parts of the chromosomes, which were shown by four parallel lines in a diagram. Well may an admirer of their work say of these lines, "It is doubtful if in any book there may be found four straight lines that mean so much."

No scientist of standing to-day can conceive, in view of all this exact knowledge of how chromosomes behave, that any particular change made in any creature's body during its lifetime can be passed on to its offspring. Heredity is now known to be a matter of a succession of germ-cells. They are the means—the only means—of carrying on the pattern of life from one generation to the next. Every germ-cell is born directly from a previous germ-cell, of which it is a reproduction. There can never be any gap in the succession. Here is a stream of life that has flowed continuously from the first nucleus to the last. It is this unbroken stream of heredity that nature cares about. The trunks of trees and the bodies of sharks and moose are only contrivances to keep the stream flowing, only a series of reservoirs for germ-cells, a series of homes in which germ-cells may be protected until they can reproduce.

Picture to yourself a stalk of corn that was growing by a New England lake when Athens was young. Its sturdy stalk mounted, its splendid leaves were thrust out, and its roots spread vigorously. When its whole body had developed, it flowered at the summit in a tassel, producing in-

numerable minute grains of pollen. Every one of these was a plan of the entire plant—root, stem and blossom—with provisions for rebuilding an entire set of the hundreds of millions of varied sorts of cells. Below the tassel had grown another set of flowers (clustered about a cob and covered by layers of husks), each of which sent out a long thread to the end of the cob; there the threads emerged from the husks and hung in a silky cluster. On to each fell pollen grains. The fortunate one in each case found its way to the hollow core of the thread and descended the whole length, to where at the base an egg was awaiting it, an egg that also had provisions for the whole organism of a stalk of corn. Into this it made its way, and the two cells combined into one. The new cell divided, mingling the chromosomes from the two parent cells and sending equal parts to each of the new ones. Each of these in the same way divided equally its inheritance. From four to eight to sixteen to thirty-two to the end there was the same equal division of the inheritance. Thus was formed an embryo of a new stalk of corn. This was the treasure for which the plant had labored. The rest of the plant's life was devoted to building around the embryo a store of rich nourishment for its next stage of life. The seed was complete—a kernel of corn. The parent died.

Through the winter the embryo slept. Next spring, when warmth and dampness had stimulated it enough, it resumed the multiplying of its cells, each of which received that equal inheritance from tassel and silk—each one of the vast aggregate that was to labor underground and in the pith and in the sharp edges of the leaves of the new plant. All their combined labor through the second summer was for one result—to build a home for the germ-cell that was to continue

the stream of descent. This was a part of its parent cell, a veritable piece of it, and it kept the unbroken stream of life flowing through the summer of plant growth and through the winter of plant death.

Its own self was in the tassel and the silk of the third summer, and of the fourth. And so long as that species of maize lives, every kernel will be a link in a continuous chain of germs back to the beginning of the species. And the first cell of maize that ever lived must have been born directly from some previous cell. There never has been—there never could have been—any gap of a single link in the succession of cells from the beginning of life on our globe. That is the "germ-plasm stream." That is heredity.

It is the force that tends to make life durable, persistent, unchanging. No wonder that Weismann exclaims about "the enormous duration of the constancy in a species." He was speaking of some butterflies that have maintained, in an unchanging form, a germ-stream for fifty thousand years. Even that period is short compared with another that we have heard of in a previous chapter—an unchanging succession of germ-cells in a tree for several million years. One genus of little bivalves *(Lingula)* has lived almost unchanged through nearly the whole geologic record to this day—so long a duration that estimates of it vary from twenty million years to two hundred million. Heredity always tends to preserve the same forms forever.

The persistent power of the current of sameness may seem even more striking if we turn from the inconceivable stretch of ages to some petty subject, say pigeons. These have been domesticated for several thousands of years and have varied in the most extreme, sometimes outlandish, ways; but if we mate two of the artificial varieties, we shall see young that

are like their ancient ancestors of Asia. Before the Babylonian Empire arose, there had been set up in the chromosomes of the wild rock-pigeon a design for bodies of a certain size and shape, covered with feathers in a certain pattern; and all the while they have carried it in the germ stream, latent and concealed; now when they are disturbed, back they go to the model that is native and deep founded. Even the useless hairs on our arms are always set according to a certain ancient, established pattern.

Do you complain that this is confusing? Do you find fault because the chromosomes are one minute described as unchanging, and in the next minute as ever-changing? You well may complain, for the statements seem contradictory. The contradiction, however, is the fact of nature. Chromosomes have those two opposite qualities. On the one hand they are never absolutely precise and may vary most wildly; on the other hand they may return from their fluctuations to their original design and reproduce it unswervingly for ages. Their variation is a fact, which was exhibited at length in the preceding chapter. Their unswerving fixity for long periods is equally a fact. If a paleontologist takes a rapid glance at the record of all life for fifty million years, he is impressed by the variation; and yet he is the very man who can give us the most striking examples of unvarying heredity. If a naturalist observes poplars and swallows from year to year, heredity seems the conspicuous feature; and yet, if he is careful enough, he will see perpetual variation. These are two inseparable truths, as opposite as the foundation and the roof of a house—and not any more at odds with each other.

They will be reconciled in the next chapter, on Selection. When we have understood each truth sep-

arately, and have then understood how they cooperate with each other, we shall have the secret of evolution.

Before we conclude the chapter we should remove from our minds a doubt that is lurking there, "How can it be," our skeptical brain keeps asking, "that the intricate pattern of heredity for a whole animal is carried in the minute space of the chromosomes?" We can not conceive that the whole of a big organism is all represented and provided for in some microscopic beads on a thread.

The only trouble is with our brain, which is to the last degree gigantic and gross in its ideas. We can not realize how huge and crass are our notions of matter as compared with what is known in the modern laboratory. If we adjust our brain to the facts of recent physics, a chromosome will seem as big as a palace, a roomy place for the architects of anatomy.

Begin the adjustment by picking up a ruler and seeing how small a distance an eighth of an inch is. Take half that distance, not a pinhead's width, and imagine a cube each side of which is one-sixteenth of an inch long. Does it seem a small space in which to stow a life-making apparatus? Only because we are like the towering creatures that grinned at the tiny six-foot Gulliver and wondered how blood could circulate in so small a heart as his. They were only six times as tall as Gulliver. If they had been a thousand times taller still, they could barely have seen the speck of a human being and would have found it impossible to believe that in him were capillaries and brain-cells. They would not have had imagination enough. If we can be unlike the giants and can stretch our minds into the realms of the microscope and beyond, we shall have no more skepticism about the capacity of a chromosome.

Descend into this sixteenth-of-an-inch cube, which

we will suppose is filled with human blood; become, as you were in the clover leaf, one-ten-thousandth of an inch tall. You are in a whirling world of twenty million disks. Most of them are of a yellow color, (the "red corpuscles"), with a diameter three times your height; each is an elaborate chemical apparatus for distributing oxygen. It is a large coarse structure. If it were a person, it could not begin to see a molecule of the protein in its system, for it is twenty-three thousand times as wide as that molecule.* It is massive and coarse and of vast size. If we wish to descend in matter until we can see something that is slightly refined, we must grow very, very much smaller, until finally we are far within the red corpuscle, and a molecule looms large before us. Even here we are disappointed, for we perceive that the molecule is massive and coarse, made up of swirling atoms. At this stage of our journey we are prepared to believe that the mechanism for making an elephant might easily be arranged for in one molecule. We must reduce by a tenth until we can pay proper attention to an atom. Lo and behold, it is massive and coarse! A physicist has written about *Exploring the Atom,* and if we wish to explore we must reduce our size, and reduce, and reduce. It is a long stage, this last one. So extended is the great reach of space before us that we are glad we are safe at the circumference of the atom, and not winging our way into its fathomless depths. Its diameter of one-three-hundred-millionth of an inch is now an illimitable field for our straining eyes. At length we see the electrons darting with fearful speed in their assigned orbits within the atom. And they have plenty of room. They are as remote from one another in proportion to their size as the earth is

*According to Comstock and Troland's entertaining account in *The Nature of Matter and Electricity.*

from the other planets. The mind can endure no more. It reels as it tries to apprehend the spaciousness of an atom.

When a person returns from such an expedition to this our region of human sensations, he has left his skepticism behind. He can exclaim with Hamlet, "Oh, God! I could be bounded in a nutshell and think myself a king of infinite space." Any space that our mountainous minds can conceive is more than is needed for the mechanism that nature contrives to carry on heredity in chromosomes. We gain in another way by such an expedition: we no longer object to calling chromosomes a "mechanism." That is an ugly and untruthful word if it suggests the coarseness of steel and steam; but now we know that it is only the organized powers, working by nature's laws, which convey from generation to generation, in the spacious chambers of a chromosome, the hereditary characters of a race of plants or animals.

CHAPTER IX

NATURAL SELECTION

I. Sifting Out the Unfit

In a school of salmon running up a turbulent river and leaping waterfalls to spawn there are some that were born too weak for such a severe test. These can not endure to the end, and so they fail to propagate. If a hundred seeds from spruce trees are lying in the soil of a vacant spot in the woods, they are not all alike; some have a weaker apparatus in their nuclei than others. When these sprout, they are doomed to failure; for the trees from other seeds can put out roots and climb for sunshine somewhat faster. So always in the struggle for existence: weakness is not excused and can never endure; it disappears.

Of all the young of any species born on a certain day a few are exceptionally well fitted to survive; some are moderately fitted, and many are not quite well enough fitted. Of course there will be casualties that come to the well-fitted and the ill-fitted alike; lightning may destroy the strong and the weak indiscriminately, and enemies may sometimes have better luck against the strong. But otherwise, and in the main, variation has doomed a few to survive through a long fight, and many to be emancipated by early death. Survival or disappearance is principally a matter of variation* in chromosomes—often a very

*For the kinds of heritable variations (the "recombinations" and the "mutations") see Chapter XXIV, Section III.

slight difference. A little more length of wing, a little less weight of bone, a little—only a little—larger breast muscles, may be the difference between life and death in securing food. A slightly thinner shell of a seed may mean that the germ can sprout a little earlier, and so get the start of others and survive them; or it may mean that the germ can not survive the rigors of winter, and so will perish.

How shall a well-fed, office-bred American understand this? He was never hungry in his life—not with a fierce, compelling hunger; his main concern with food is to refrain from eating too much of it. He must stretch all his powers of imagination and sympathy if he would understand what variation means in the competition for food. He would have seen an illustration if he had gone on an army transport, during the Spanish-American War, from San Francisco to Manila. For thirty days the steamer plowed her way across the Pacific. In her wake were some gulls that needed food, more than they could find in the crowded competition of San Francisco Bay. They were not enjoying travel for travel's sake; they were struggling for the scraps that were thrown from the cook's galley; and all their strength was needed to survive. The gull that could endure for only twenty-nine days would perish.

We know by actual measurements that all birds do vary in structure and power. "A variation of from fifteen to twenty per cent. may be ordinarily expected among specimens of the same species and sex, taken at the same locality."* And we know, furthermore, that variations much less than that may preserve from death. A captain of a ship in the Atlantic once made these two entries in his log when he was one hundred

*Quoted in Wallace's *Darwinism*, from which come the data for this paragraph.

and sixty miles from land: "A great many small landbirds about us; put about sixty in a coop, evidently tired out. . . . Over fifty of the birds died, though fed." They had been blown to sea while migrating, and only one-sixth of them had power to survive. A flock of one hundred and thirty-six sparrows, driven by a hard wintry gale, exhausted and numbed with cold, were once taken into a laboratory of Brown University. In spite of the best care, sixty-four died. Accurate measurements were made of the living and the dead; tabulations showed that the dead were (1) slightly larger, (2) slightly heavier, and (3) had slightly shorter breast-bones. That is, those birds which had weaker breast-muscles in proportion to their weight could not endure the storm as the others did. In this case the difference between life and death was a difference of only one and one-third per cent. in the proportions of parts of the anatomy. Such variations, and much greater ones, are always to be found in a flock of wild birds; the favorable variations will, in the long run, survive.

This fact that only the best adapted plants and animals can live is called Survival of the Fittest. Or, since nature seems to "select out" the unfit and remove them from the struggle, the process is figuratively called Natural Selection—the name that is now in more common use. It is a name that misleads the unwary.* Nature is not a breeder and does not "select." What actually happens is that the less fit do not survive, while the more fit, or the fittest, do survive.

*Darwin coined the phrase as a kind of parable, in which nature is represented as "selecting" the best variations, as being a kind of breeder. Though he defined it carefully as including both "preservation and destruction," his parable has always confused literal minds. It misled John Burroughs so completely that he accused Darwin of being anthropomorphic!

What will be the result of natural selection as it operates unswervingly through the centuries, always removing some variations and leaving others to reproduce? The answer is not easy to read in nature, because most of the results are brought about very slowly and were fixed long ago. But we can see an illustration of one part of the process by watching another kind of selection in artificial conditions. We can see how breeders of animals and growers of plants select variations for a series of generations. They work on a principle opposite to nature's, but they can give us the clue to natural selection, just as an artificial electric spark in a laboratory gives the clue to understanding a stroke of lightning that is formed by nature in a very different way.

A breeder selects variations for his human purpose —often a freakish one—of securing a result that has more meat or more expanse of petals. What we can see in his process is *a series of variations that are inherited and that result in a different kind of creature.* That is what we need for an illustration, because that part of the process is what occurs in nature. But we can use nothing more. The breeder and the breeder's purpose are utterly different from nature.

II. Artificial Selection: Preserving the Unfit

The wild rose of Scotland has only one set of petals, arranged in one flat disk; it is a single flower. The idea once occurred to a Scotch florist that this blossom would be more beautiful if it had more petals, if it were double. His way of operating is an example of all those ways in which plants and animals can be adapted to man's fancy if the unfit are allowed to survive.

He did not begin by tampering with any seeds or

blossoms; he did not do anything to any plant. He simply examined a great many flowers. Of course he found that heredity had been making the blossoms all very much alike; all were single and five-petaled, similar in size and color; he might have looked at thousands of blossoms before finding a variation from this pattern. But he knew that variation is bound to occur and is bound to be discovered by any persistent searcher. He persevered till he found a blossom that had one extra petal, which was growing inside of the regular five. This sporting flower he marked, and in the following fall preserved the seed-ball. So much for the variation part of the program.

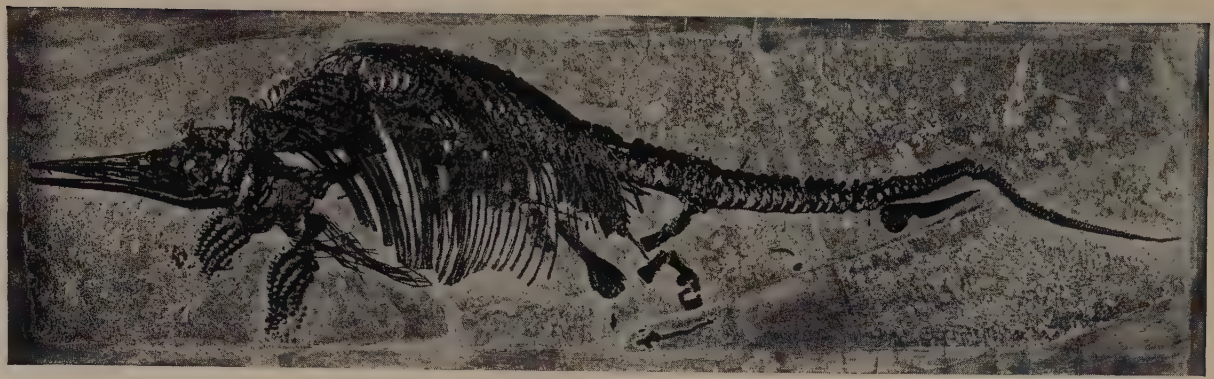
The florist knew that any such variation, even if it is abnormal, may be inherited. Next spring he planted all the seeds, and in the summer scrutinized the flowers. Three of them had inherited the extra petal. All the normal blossoms he destroyed, and next spring planted the seeds from these three unnatural ones. Ten blossoms inherited the extra petal. To an impatient man this is not much of a result for three seasons' work, but the gardener was quite contented, knowing nature's ways and knowing that it takes a little time to break up the habits of long ages of inheritance of what is adapted to the struggle for existence. Next year a number of his blossoms showed a whole extra row of petals, and the doubling was under way. Within ten years he could show in his garden a flower that had six rows of petals. In so short a time had the pattern of the chromosomes been altered and a new one substituted. The double flower now had a changed heredity apparatus with respect to the number of petals; this followed the new model and has regularly produced, generation after generation, to this day, roses with many rows of petals.

But it is artificial, made by the fostering care of man. If it were turned out to shift for itself in nature's struggle for existence, it would probably prove unfit and would perish.

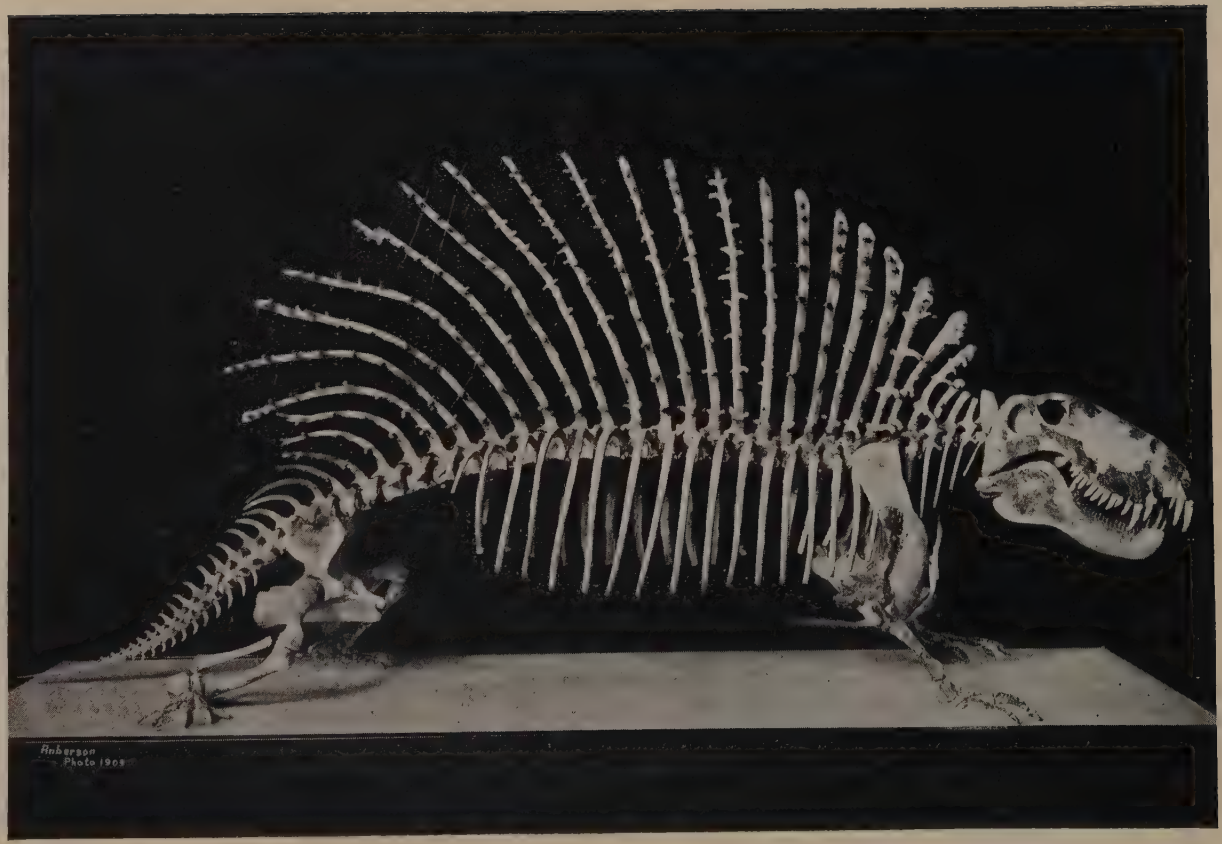
That process of making a new kind of blossom is always the course of artificial selection. Man can not begin the operation. Nature has to make the beginning. In some egg it happens* that the chromosomes are somewhat erratic, that they depart from the ordinary model. Why they vary no scientist knows—possibly no scientist will ever know. We can see the effects and can take advantage of them, just as an animal trainer can see the effect of a whip or a reward of food, though he never expects to know what makes the cells in the animal's brain behave as they do. We know that there is a complicated mechanism in chromosomes which never works with absolute precision, and we can see the results of their varying. That variation arises, suddenly appears, in a flower or a nose or a leg. When it has appeared we know that it is an alteration in the germ-stream of life, and so can become an inherited character if it is carefully preserved. We can thus manipulate heredity. This finding of a variation and then developing it by preserving characters that are adapted to man's wishes is artificial selection.

The human race was practising selection before the dawn of history. The earliest lake-dwellers in Switzerland selected variations in wheat and kept alive artificially a plant with plump grains that could not maintain itself in the struggle for existence. The

*Of course nothing can "happen" without a cause. Every "chance" variation was produced in accordance with fixed natural laws. But we know nothing about the cause. When a scientist uses such words as *happens* or *by chance* or *fortuitously*, he always means "produced by unknown causes." See Section V of this chapter for a discussion.



This reptile, an Ichthyosaurus, became, like the modern whale, adapted for life in the ocean and used to swim where Germany now is. The specimen is a female, about 30 feet long; several of her unborn young were preserved with her.



One of the early reptiles, with a monstrous development of the spine, which was not successful for long. A full account of the order of evolution of all the reptiles, with copious illustrations, is given in R. S. Lull's admirable *Organic Evolution*, from which some of the information for these legends is taken.

earliest North American Indians must have lived on the small kernels of a wild plant, in which they detected small variations; they selected the larger kernels for planting and developed "corn." So long continued was the selecting in these cultivated cereals and so far were they trained away from the original forms that now the botanist can not tell from what wild plants they descended. And the variation is not at an end. To-day more than ever the agriculturists are noticing variations, selecting them for food values, and shielding them from the struggle for existence.

All our grains have been found by the same process, all the vegetables in our gardens, all the fruit trees, all the cultivated vines, all our beautiful garden flowers. Everywhere in the world to-day men are looking for variations as if they were prospecting for gold. They can no more make variation than they can create a precious metal; they can only seek for the gifts which the chromosomes have created here and there. To be sure, a gardener who wants variations in a wild plant may stimulate them by putting the plant in richer soil; but this is only hastening the variations or setting them free. Nothing but chromosomes can originate a variation. The first step of all selection in garden vegetables or trees or flowers must be to search for what some unknown power has made. A variation may be a great leap to something startlingly new—like the bellflower apple—or it may be an infinitesimal step; but, large or small, it is caused by some sort of change in the chromosomes of the germ-cells.

When variations are closely observed in a plant and carefully selected through many generations, they may be led into extremes of size and shape. The species of one genus *(Brassica),* which still flourish

in their wild state as insignificant little weeds, have been worked into a great variety of vegetables. One of them has been developed into a cabbage, the head of which is unlike anything in nature, and into a cauliflower, and into Brussels sprouts. A second species has been selected along two lines: at the end of one is the turnip root, and at the end of the other are the oily seeds of the rape. A third species is mustard.

We all know what selection can do with flowers. It brings a yellow single flower from Brazil to France, doubles it, increases its size, and gives it all the forms and colors that are annually shown in the Bronx Park exhibits of dahlias, at the last one of which "Uncle Sam" was pink in color and nine inches in diameter. Artificial selection takes a Chinese daisy and enlarges it to a mass of yellow bloom, a chrysanthemum, twenty inches across.

Cabbages and chrysanthemums are adaptations to the wants of man, but not to the struggle for existence. They are flabby unnatural plants that can live only when they are removed from the competition of nature—from natural selection.

As with plants, so with animals. Before history began, men had been selecting, almost unconsciously, the differences in dogs. By the time the records open, men had many kinds, most of which could not have survived in the struggle for existence. There were slender hounds for speed and silky ones for pets. Man has manipulated the race as if it were so much clay, fashioning now a little helpless, hairless creature, now a squatty fighter all front legs and jaw, now a big friendly brute with woolly coat, otter-hounds that have developed quite a web between their toes, a collie that has become highly intelligent, a stupid Chinese dog that is fed on vegetables and is used for food. We can

set no limit to the molding of animals that may be possible in the future. Horses have been shaped into grayhound forms for racing and into almost elephantine forms for hauling drays. Pigeons have been bred with monstrous tails, with enormous "pouting" breasts, with long wattled noses, with beaks so short that the young can not peck their own way out of the shell. Pigs have been made so fat that they are no longer like real animals, but are a sort of meat factory on legs so short as hardly to keep the body off the ground. Man has gone even farther than this in opposing the course of nature; he has preserved for his amusement demented mice that spend their lives in whirling round and round; he has fostered disordered birds that "tumble" in the air.

Not all of these artificial creatures are weak. Darwin warns us that "we must not overrate the difference between natural species and domestic races; there is no palpable difference between them. . . . Domesticated races propagate their kind far more truly, and endure for much longer periods, than most naturalists are willing to admit." The bull-dog and the game-cock are certainly strong, and some cultivated plants are hardy if left to shift for themselves —buckwheat, for instance, will choke out morning-glories, a most powerful weed. But the bull-dog could not run down prey nor the game-cock scratch for food with his spurs if they were turned out to compete for a living in nature. It is not a matter of "strength" or "weakness"; it is a matter of being adapted, fitted. The strength of the fiercest bull-dog may not fit him to survive in nature; whereas the flabby "weakness" of a parasite may fit it admirably to survive.

All artificial selection—though opposite to nature in purpose and result—shows strikingly one element

in natural selection: that certain types of variations are inherited, and that the inherited characters can increase by further variation, and that by selecting a series of such inheritances a plant or animal can be gradually altered into a new form of life. Every organism is plastic material that can be molded by selection. But selection merely takes what nature provides in the form of variations. It creates nothing itself.

In the short time that man has been systematically altering natural forms he has never made such transformations as putting horns on pigs or shifting eyes to shoulders; but within limits he can decide what he wants and can then build to attain it. He can shape a rooster's comb, or the shoulder or the eye of a cow; he can alter the grain of the meat in a hog or remodel a canary's head. A successful breeder has a "prophetic vision," and that which he foresees he can make by selecting the variations that germ-cells create.

Artificial selection is not limited to animals that have been long domesticated; it is a process that is always seen when man breaks into the struggle for existence at a point where nature was never interfered with before. One experimenter* bred some little fruit-flies that showed slightly abnormal veins in their wings, removing from each generation those that were normal and allowing the abnormal to breed. In the sixteenth generation all the young were born abnormal, though in nature only one in three hundred is abnormal. Then the experimenter reversed the process. Starting with an abnormal pair and removing—"selecting out"—all the flies born with abnormal wings, letting those that were normal breed, he produced a sixth generation that was one hundred per

*Frank E. Lutz, *Carnegie Publication 143*. This report is illuminating and significant.

cent. normal. By selecting for twenty-two generations he had made a round trip in variation.

When successive generations of young flies are carefully observed, many kinds of variations are seen: some have limber wings, some have short wings, some have poor eyes. The new forms are not caused by artificial conditions, but are such as frequently appear in nature. They are healthy and will breed if they receive food. Why, then, do such forms never breed in nature? "Wild rabbits," says Wallace, "are always of gray or brown tints, well suited for concealment among grass and fern. But when these rabbits are domesticated, without any change of climate or food, they vary into white or black, and these varieties may be multiplied to any extent, forming white or black races." These white and black colors are not new characters caused by putting wild animals into pens; they are variations that continually occur in nature. Why, then, are white and black rabbits never found in nature?

Guinea-pigs normally have three toes on each hind foot, but once in a great while a specimen is found that has four toes on one hind foot. Such a rare animal has been bred; all the offspring that did not inherit the fourth toe were selected out; all that did inherit were allowed to breed. In the fifth generation ninety-seven per cent. of the young had four toes on *each* of their hind feet.* Why has no such race developed amid the struggle for existence?

The variations that have been described occur repeatedly in nature, but regularly disappear. Does this, then, mean that nature never tolerates variations and never practises selection? The answer is in Section III.

*W. E. Castle, *Carnegie Publication 49.*

III. Natural Selection: the Survival of the Fittest

The man who made "the round trip in variation" of fruit-flies has observed in another set of experiments* what happens to variations in the struggle for existence. He studied crickets on Long Island, near Oyster Bay, where a corps of experts work at the Station for Experimental Evolution. He collected specimens in four places: (1) on the mainland, where the soil was good; (2) at the base of a sand-bar, where the soil was poor and sandy; (3) in the middle of the narrow sand-bar, which ran out seven hundred yards into the water; (4) at the tip of the sand-bar, where there was no soil, but only pure sand. He measured on every female cricket the length of the egg-laying tube, the "ovipositor," that protrudes, long and prominent, from the end of the body. The average length of the ovipositor on the mainland was eighteen millimeters (eighteen-twenty-fifths of an inch); the average length at the base of the sand-bar was nineteen millimeters; in the middle of the bar nineteen and one-half; and at the tip twenty. The varying lengths were neatly assorted for these small differences. Here was a most curious proof that some kind of selection had been made—as obvious as if you should enter a room and find four piles of firewood neatly sorted out according to lengths. Such assortment could not be an accident. No more could these crickets merely happen to be arranged in groups; for the same measurements could be found year after year; the crickets do not migrate much in any season, but inhabit their regions for generations. Some force had been selecting. It must have been a very discriminating force, for it worked with differences of one-fiftieth of an inch.

If you asked a savage what did the selecting, he

*Carnegie Publication 101: *The Variations and Correlations of Certain Taxonomic Qualities of Gryllus*, by Frank E. Lutz.

would reply that some spirit, some sort of intelligence, had been herding the crickets into bunches. But the Cold Spring Harbor experimenters have found no sign of any spirit. If you ask the first intelligent, non-scientific man you meet, he will probably say, "Oh, the rich soil makes ovipositors fat and short, while the sand makes them long and lean." The intelligent man is giving the answer that seems always to spring up in the human mind—the idea that the environment causes changes and that these acquired characters are then inherited. Even trained minds that know an outline of evolution, show a strong tendency to slip into the old, baseless, impossible explanation.

Only by keeping our eyes on the chromosomes can we hit the truth. Of course the truth is that all such selection must have begun with germ-cells. The length of egg-layers is very variable. In other localities crickets thrive with an implement only fourteen millimeters long; and where the average of the population is nineteen millimeters, no two specimens will have ovipositors of exactly the same length. That variability is the beginning of the right answer. The next part is readily found by looking into the struggle for existence of crickets. In the fall they lay their eggs in the ground: in one locality fourteen millimeters is deep enough (supposing for convenience that the depth of the hole equals the length of the egg-layer), but at Cold Spring Harbor it is not nearly deep enough; even on the mainland an egg buried only seventeen millimeters may be destroyed during the winter. *A mother who buries her eggs less than eighteen millimeters may not have offspring next year.* In the middle of the sand-bar the egg must be slightly deeper if it is to hatch; in the sand at the outer end no young will survive if the mother probes less than twenty millimeters.

The answer is complete when we inquire about heredity. If any germ-cell fails to produce a long enough ovipositor, it will not survive in daughter cells, in the germ-plasm of the next generation of crickets. Every mechanism that produces a proper length has a good chance to survive in the next generation. All the germ-cells of the next generation which are true to their inheritance will have a good chance to survive; *and all that do not follow the successful model will perish.* The winter's cold selects germ-cells more neatly than if it were intelligent.

To be sure, there are all manner of exceptions to this cut-and-dried summary of a case of natural selection: a female with a shorter ovipositor might push an egg deeper than one with a long tube; during one winter less depth of burial is needed than for another winter. We can never know all the ins and outs of even a simple example of the struggle for existence. But the principle is truly set forth. Temperature and soil conditions can select unfavorable variations of crickets, and thus gradually alter their forms, more surely than any human breeder could.

Nature works surely, and in the long run works exactly. But in any one season selection may be very irregular. Some of the best-fitted animals may die by accident, and some of the unfit may have the good fortune to survive. There is no precise standard of what is absolutely *most* fit. Nature, in general, destroys those animals that are *less well* fitted for the struggle. The fact is that natural selection is "survival of the fitter"—it is a comparative matter. It may happen, also, that some weaker animals, cut off from competition, can survive for a longer time than others that are stronger but that live in fiercer competition. All is relative. We can only say that in any set of conditions the animals that are more fit have a better chance to survive.

The impersonal forces of nature alter the dimensions of an animal in ways that are less direct than in the case of crickets. It was once found that the crabs on a beach near Plymouth, England, were growing slightly narrower. Careful measurements in hundredths of inches showed unmistakably that a general progressive change was going on, that some force of nature was selecting out the broad crabs and killing them. So the puzzle was: "What change in the environment is putting broad crabs to death?" One shrewd observer guessed that the cause might be an increased amount of clay in the water, for it was known that the working of more land up the river had caused more clay to be washed to the ocean, and that the very fine particles of the clay kept the shore water somewhat muddy. An experiment in a laboratory proved that the guess was right; for if a lot of crabs were kept in a tank of slightly muddy water, the broader ones died. No one knows the reason why the broad crabs can not live; their mere breadth can not be the cause; it happens that the broad ones are constitutionally unable to resist muddy water. Here was a demonstration that year after year the clay particles from the river were removing a certain variation among the crabs—just as certainly and just as accurately as the temperature of different regions selects certain unfit crickets. If a great deal of clay had come down the river some spring, all the crabs might have perished at once. But since it increased gradually, it first selected only the very broad ones, next year those not quite so broad. Each year there was a weeding out of all crabs that varied toward broadness; and there was time for the variations toward narrowness to develop and survive, "leading to a change in the proportions of these crabs, which, if continued at anything like the same rate even for a

century, would so alter the shape of these animals as to produce what would certainly be described as a new species. . . . There seems little doubt that we have here a means of seeing natural selection actually at work."

Natural selection is as impersonal as sea-water and climate; it has no design, no purpose; it molds heredity as mechanically as waves shape the rocks. It can not create a species any more than waves can create granite, but can only pound away at the variations that perpetually occur in every stream of germ-plasm. In the nutmeg tree, for example, there are constant variations; climate and competition pound away at the unfavorable ones, which are never allowed to propagate. If man interfered with the nuts, he might preserve variations of the rind that were slightly more pulpy, and by a long series of such selections, taking advantage of any sports in this direction, he might convert the bitter rind into sweet pulpy fruit—just as the bitter rind of an almond could be altered into a peach. Man could do this by design. The forces of nature select out from the rind every tendency to sweetness and pulpiness; any nut that has a slightly sweet or pulpy cover is not so well protected and will have less chance to reproduce itself.

Natural selection has no power to help a plant by causing a favorable variation. If the crabs had not possessed in their germ-cells the apparatus for growing narrower, if the nutmeg had no apparatus for producing a tough and bitter rind, natural selection could not operate. Insects could often lay their eggs to better advantage, but no useful variation of instinct happens to arise, and the females continue to blunder.

Variation is not a matter of mere visible alterations; it occurs in all the fluids and organs and cells of every part of all bodies; chemical components vary,

After looking at skeletons we are apt to forget that the bones were once clothed with flesh and that the hungry animals had to eat. This one, Brontosaurus, was a vegetarian, 67 feet long, and weighing 38 tons.

Some of the inhabitants of Nebraska only a short while ago—say ten or fifteen million years.

and nervous adjustments. A very important organ of earthworms, which normally is in two parts, may sometimes occur in three or four parts; an important duct may open anywhere from the tenth to the sixteenth segment. Some birds and giraffes lack a gall-bladder, and sheep have been found with three gall-bladders. Here is material—if it originated in chromosomes—for natural selection to work on. Such variability in every generation means that worms and giraffes and sheep can be adapted to new conditions of life, that if one sort of variation is rigorously removed, another is ready to prosper and increase and predominate in heredity.

A peculiar and spectacular variation that seems to be rather common among larger animals is a big shift in the proportions of the jaws—the "bull-dog type" of face that sometimes appears in cattle and pigs. Fishermen occasionally find a "bull-dog cod"; this seems poorly adapted for life on the floor of the ocean, but it persists in appearing once in a while and might, if conditions changed, become the regular type. There used to be semi-wild cattle on the ranges of Argentina that had a bull-dog type of head—the lower jaw protruding, the upper lip receding, and the incisor teeth exposed. These are hardy enough ordinarily and are a favorite breed; but in a dry year, when the grass is short, they can not crop so close and would starve if man did not feed them. All about them, in that last inch of grass which their short upper lip can not get hold of, there are tons of good food, but they are powerless to pull it into their mouths. The bull-dog type seems to be continually seeking its chance in many parts of the animal kingdom, but is always removed by natural selection. It is an interesting example of the wealth of variation that selection has to work on.

Such a case shows that germ-cells are as ready to continue making one type as another. Professor Morgan found in his abnormal, unfit fruit-flies that "adaptive characters are inherited in exactly the same way as are those that are not adaptive." So variation is forever furnishing the material of adaptation, and heredity is always prepared to preserve it; the result is determined by the way in which the struggle for existence destroys forms or allows them to develop.

Canaries were for untold centuries a green bird. For some reason the occasional yellow sports could not succeed—perhaps because they were more easily seen by their enemies. After canaries had been bred in captivity for two hundred years, they were still green birds. But then a sport to yellow was fancied by one breeder, and this became fashionable. Nevertheless, after the green color had been ruled out by artificial selection, heredity could still be counted on to furnish occasional green birds. It acts the same way in nature. When rats or dogs or rabbits or cattle are turned out in new surroundings to run wild, the operation of natural selection is always seen. "It has happened on two or three occasions that European rats have been accidentally imported by ships upon some of these islands, and even already it is observed that their descendants have undergone a slight change of appearance, so as to constitute them what naturalists call local varieties."* We can not guess at the obscure ways in which natural selection acts on such immigrants—why in the new surroundings a slight variation that used to be favorable and predominant is now unfavorable and perishes. But so it always is. "When an animal has to struggle under circumstances inconceivably complex," says Darwin, "modifications

*G. J. Romanes, *Darwin and after Darwin.*

of the most varied nature in the internal organs as well as in the external characters, will be rigorously tested, will be preserved or rejected."

In Europe a certain species of lady-beetle shows many variations of coloring, but for some reason these are selected out much more rigorously in America, and the color pattern remains very constant.* Another species has a much more constant pattern in the West than in the eastern states. A third species shows changeable stripes in the East and constant ones in the West. For reasons quite beyond our ken natural selection bears harder on a variation in one region than in another.

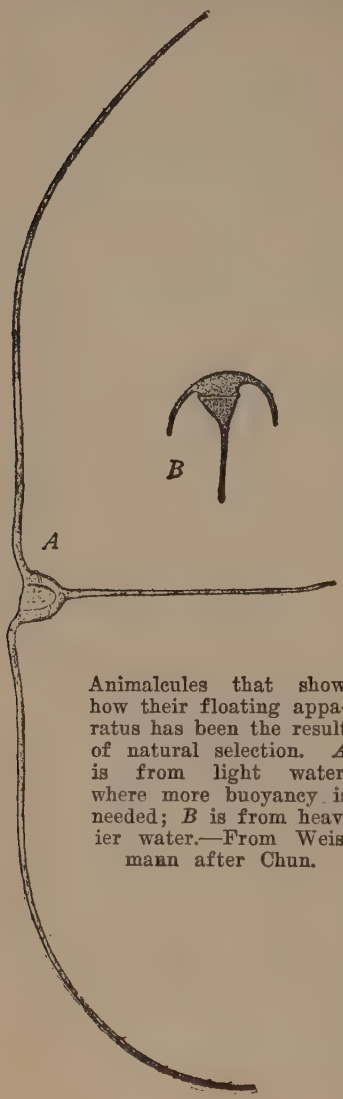
These minute studies of spots on small insects may seem petty business, but there is as much meaning in those varying colors as in the prodigy of an ancon sheep. Colors may be matters of life and death to animals, and any differences in them are the result of severe and accurate selection in the competition for life. What is more, every spot of color was provided for in the pattern that a chromosome inherited and then transmitted. Here we can see how nature sifts out some variations and permits others to reproduce, though we have no clue to the reason.

But sometimes we can understand the action of natural selection. One kind of animalcule,† living in all the oceans of the world, gives a beautiful exhibition, as clear as any chart, of how the changes in germ-cells are sorted out. It is shaped like an anchor. From its lumpish body branch the slender, tapering stem and two slender, flexible arms. These arms are floats to support the animal at the right depth in the water. It will need longer floats if the water is less

*R. H. Johnson, *Carnegie Publication 122, Determinate Evolution in the Color Pattern of the Lady-beetles.*

†A genus of the Peridineæ, *Ceratium.*

buoyant, just as a person needs a larger life-preserver in a fresh-water lake than in the heavy water of the Great Salt Lake. Hence we could predict that if one of the animals is born with arms too short for light water or too long for heavy water, it will be floated at the wrong depth and will perish, leaving no descendants. Investigation shows that this is exactly what happens. In the Gulf of Guinea, where the water is light because of its warmth and its small amount of salt, this creature's horns have to be ten times as long as its body. But just in proportion as the water grows colder and saltier, so that it is more buoyant, shorter horns are needed. In one of the ocean currents the same size of body is floated by horns only one-tenth as long as are needed in the Gulf of Guinea. Salt and temperature do not manufacture horns. But they do most accurately select out and destroy all those animalcules that vary in a slight degree from the propor-



Animalcules that show how their floating apparatus has been the result of natural selection. *A* is from light water, where more buoyancy is needed; *B* is from heavier water.—From Weismann after Chun.

tions that are needed in any given part of the ocean.

The longer a naturalist studies, the more he sees natural selection everywhere and always at work. He learns to decipher the stories of adaptation as if they were written in a book. But the language is a foreign one which he has to learn to translate. When he has become expert, the queer idioms of adaptation grow familiar and sensible, until at length he can make out a clear and consistent message of evolution.

IV. How Natural Selection "Makes" Adaptations

I will give a few common and brief examples of how the nineteenth-century naturalists learned to read the record of nature and to find out how adaptations were "made." This knowledge has been so much extended in the twentieth century that science now constructs the histories of species almost as confidently as if it were telling of Rome and Thebes.

There is a species of nut-jay which ranges from the Alps to Siberia. In the Alps it has to get food by breaking up pine-cones, and there it has a thick bill that is well adapted for such hammering. But in Siberia it can not secure food that way; it has to reach into cedar cones, where the seed lies deeper than in the pine; and in Siberia it has a bill adapted for reaching—longer, more slender, with the upper jaws protruding a tenth of an inch over the lower. The history is easy to read if one knows the language of chromosomes. When the species originated, those birds in a pine forest that varied toward slender bills could not live through a hard winter when the competition for food was keen; and in a cedar forest those that varied toward stubby bills could not survive a hard season when there was not food enough for all. In this struggle with cones and cold the unfavorable variations

were selected out; and as the centuries went by these two impersonal forces were the cause of adaptations.*

There is a genus of butterflies, widely distributed over the earth, that offers a puzzle in colors: in some species both males and females are brown; in others the males are bright blue, while the females are brown; in some species the males show only a trace of blue. This genus used to be as much a mystery as Aztec inscriptions; nobody could read its history in the blue and brown wings. But the record is easily deciphered when we use the key of sexual characters: the scent-scales and the blue color are male variations —like the spurs and plumes of birds. Those species that have neither character must be the oldest, and those in which the males show a slight color must be of more recent origin. If the males are bright blue and have well developed scent-scales, they must be more recent still, for variations never go backward along the same track. Younger still must be any species in which some females show a trace of blue, for this sex-character begins in males and goes from them to the females. The spread of blue shows the comparative youth of a species. We should expect that as time went on a species would develop in which all the females would be a full bright blue. And this is the case. In the tropics, where selection seems to work faster, one species has already gone to that limit. It must be very young—as time goes for the biologist. The student of butterflies is as sure of this as a historian who states that Alexander the Great occupied Egypt before he invaded India.

All through the animal kingdom enemies have selected variations in the most remarkable ways. If a little bird is colored like its surroundings, the hawks

*This and the two following examples are from Weismann's *The Evolution Theory.*

soaring far above are less likely to see it; it therefore has a better chance to survive. But if it is conspicuous, it is likely to perish and leave no descendants. It is for this reason that, as a rule, white birds can not survive among green trees and that white pigeons are more preyed upon than colored ones and that dark-colored birds can not survive in arctic snow; experiments prove that if insects and birds are put among foliage to which their color is not adapted, they are quickly killed off. And this has always been true in nature. If germ-cells of insects happen to vary in such a way that they make a color pattern which is more conspicuous in the surrounding foliage, they doom the insect to death; if they happen to vary a little toward a concealing pattern, they make an insect more fit for the struggle, more likely to survive. As the centuries go by, those unfavorable habits of chromosomes are continually being sifted out; every favorable tendency is more likely to be inherited. In this way the birds, by killing insects that have unfavorable variations, gradually bring about the most extraordinary alterations of the colors of insects, until the patterns of the wings and bodies imitate the appearance of the leaves or bark upon which they live.

If a certain fly succeeds better in having its eggs hatch because a variation has made it look a little bit more like the bees in whose cells it lays the eggs, its fortunate variation will have a chance to reappear in some of its offspring, and thus they will be more likely to prosper. Such a variation tends to continue and to increase. Those flies in the third generation that have more favorable bristles or shape of body will have success; and so the spurts of variation are slowly directed in a course that may finally lead to the most incredible resemblances. If chromosomes shape a duckling that is somewhat better

camouflaged than its fellows, it is more likely to survive and continue a stream of germ-plasm that has possibilities of varying still more toward useful colors. If a non-poisonous snake happens to be born with color spots that give it even the slightest resemblance to a venomous species, it has a somewhat better chance to survive and to set going a series of variations that approach more and more nearly to the venomous appearance. Its enemies are constantly allowing the favorable spots to survive and thus in time may bring about a case of mimicry that seems too strange to be true. But the imitation is a fact in Brazil; the evidence is so clear that experts are forced to accept it.

It is hard to believe that a bee's sting was gradually built up by a series of selections of "accidents," and the development of such an instrument as a hawk's eye is a process that makes the imagination blink. Certainly we should like to have some one discover an easier theory than natural selection.

But all the present signs are that natural selection has come to stay.* It is approached in so many ways, it can explain so many conditions, it is so in accord with the plain facts, that it grows in force every year. It has shown two generations of naturalists how the plants and animals became what they are. It can sometimes be seen at work; and whenever we assume that it has been at work, we secure a sensible result. The man who has used natural selection for many years does not feel that it is in the least weird. What staggers his imagination is to try to think how he could live without it.

One illustration among the caterpillars will show how the practical naturalist finds that the theory will lead him right. The caterpillar of the death's-head

*The evidence for this statement is given at some length in Chapter XXIV, Section IV.

moth is colored in such a way that it is conspicuous on potato plants in Europe; it has to protect itself by eating at night and burying itself in the ground during the day. This appears to be a case where selection has not adapted an animal to its surroundings. But the caterpillar is not a native of Europe. In its original home, Africa, its color is a most elaborate "imitation" of the leaves of the plant on which it feeds. There it stays out on the leaves all day long.

To tell all about adaptations in animals would be to describe the whole animal kingdom. To give a slight outline would require a book. (Wallace's *Natural Selection* is a readable one.) Here we can glance at only a few points of the panorama of adaptations. The most useful will be some examples of how often a long series of adaptations, graded from a crude beginning to a finished product, are spread before our eyes in the world about us.

If I take up a lobster's claw* and ask myself how it was developed by selecting chance variations, I am utterly at a loss. Yet a student of sea life has seen the series of steps. He can take out of the ocean specimens of a dozen different species and set them in a row on his table to show the following graded series: (1) a leg, the last joint of which can bend against the next joint and clasp an object there; (2) some roughening of the last joint, so that the object is held more securely; (3) a protruding of that next joint, till it forms a better surface for the last joint to work against; (4) an enlarging and curving of the last joint; (5-12) further steps of the same sort to a real claw. The student does not have to depend on a theory; for the principal steps, the ones that are hardest to believe, are before his eyes. In a similar way, and

*This and the three following examples of development are from the *Origin of Species*, and Huxley's *On the Study of Zoology*.

with no exercise of fancy, the student of anatomy can go a great deal further, can trace back from the developed leg to a mere jointed ring of the body; he can look further back, down the vista of development, seeing the complicated parts grow simpler, until the lobster looks almost like a jointed worm.

Does it sound fanciful? Huxley once said to an audience, after he had outlined this course of development, "I imagine I hear the question, How is all this to be tested?" He declared to them that there was a time when "endless dreams about the development of structure threatened to supplant science," and he had to prove to his classes that what he told them about the evolution of the lobster was not imagination. He began his proof by saying, "Our lobster was once an egg." He described the development of this, telling of "the rings that are first sketched out," "the bud-like prominences on them," "the growth of these into appendages"—in short, the living proof, in an embryo, of the anatomist's theory. "These," he said, "are wonderful truths—the more so because the zoologist finds them of universal application." Some description of them is given in Chapter XVII. They are the sort of confirmation that no biologist can resist to-day.

In the whole development of the lobster there is no sudden miracle, no alteration which does not come by slight changes that seem easy to account for. In all the elaborate machinery of legs and claws there is little that is really new, for most of it has been made by merely *altering the proportions.* In the case of animals it has been estimated that ninety-five per cent.* of all the evolution is nothing but the extension of some parts and the reducing of others. The continued altering of the proportions of the parts of an

*H. F. Osborn, *The Origin and Evolution of Life.*

animal may result in a creature that appears utterly different. The same is true of the altering of parts of simple plants to produce the higher ones. It is the series of gradual changes of proportions that drive a botanist to rely on evolution. He can in most parts of the vegetable kingdom arrange a set of plants, graded by slight differences from each other, that lead up to the same steps by which he had reasoned that natural selection might have developed the plant that he is studying. If he has asked himself how an iris came by its very peculiar apparatus of pistils and stamens, and if by his knowledge of how insects fertilize flowers he figures out the probable steps of adaptation, he can gather a set of blossoms that will parallel his reasoning. You recall Darwin's description of the orchid that gave bees a ducking in order to get itself fertilized, and you are skeptical as to how any process of selection could build such a tricky bath-tub; but from the seven thousand species of orchids a series could be arranged that would be almost like a moving picture of the gradual development. When a botanist has compared for forty years, in many countries, the slight degrees of adaptation that fit the different species of orchids to slightly different insects, he believes in evolution as firmly as a traveler believes in railroad trains. A savage can not believe that steam will drive an engine, and he will argue the matter; but the civilized man buys a ticket, confident of being hauled to his destination. So the scientist no longer debates evolution; he uses it. He may have some wrong ideas about *how* it operates, but he knows that it works.

The road-bed of belief in evolution is the *graduated series* of forms. An adaptation does not stand by itself as an isolated marvel, but is in a series of rather similar adaptations, a series that carries a

zoologist easily to his conclusion. Perhaps the ants come nearest to being unlike anything else in the world; it might seem that here at least we could not explain the peculiar arrangements by any process of selection of variations. Think of their three kinds—the queen, the male drones and the neuter workers. Yet a zoologist, familiar with a thousand kinds of variations of sex in all parts of the animal kingdom, could arrange a list of sex-adaptations that would represent the course of development in ants. There is nothing exceptional about these sex-groups. Nor is each sex-group made up of invariable creatures that are all of a kind. "The neuters of these British ants," says Darwin, "differ surprisingly from each other in size and in color and in their eyes; yet the extreme forms can be linked together by individuals taken out of the same nest. . . . The difference between neuters of this African ant was the same as if we were to see a set of workmen building a house, of whom many were five feet four inches high and many sixteen feet high; the larger workmen had heads four instead of three times as big as those of the smaller men, and jaws nearly five times as big; the jaws differed wonderfully in shape and in the form and number of the teeth. . . . Yet these sizes *graduate insensibly into each other.*" That is what an observer always finds—variations that graduate into each other. He can see a long course of changes, which stretches without a gap from one form to a very different form. Nature is always setting before him these exhibits of how variations have been selected and of how readily the development can be continued.

If I think of the delicate, almost intelligent tendrils of a climbing vine, I can not imagine any graded series of plant apparatus from the stem of an oak to the clasping coil of a sweet-pea. I am skeptical

and ignorant. But the botanist can not think of tendrils except as graduated series of development from other parts of a plant. He knows that in one vine they have developed from branches, in another from leaf-stems, in another from leaves. He knows many kinds and degrees of tendrils. He has seen, in plants that have no tendrils and never climb, how the young stems move in their growth, tending to go round and round in a spiral. To him the tendril of any plant is just one example of the selection of favorable variations; he can think of it only as part of a graduated series of such adaptations. If you removed this evolutionary conception from his knowledge of plant life, you would paralyze his knowledge.

All students of nature would be staggering in the dark if it were not for that conception. By its light they can read the world of life as it is and can see far back through the geologic ages. In its beams they see the variations of a four-toed animal no bigger than a cat, which were selected for three million years, till three of its toes disappeared and its size increased tenfold—and it was domesticated as a horse. The searchlight of evolution shows up the fossil history of an animal in Egypt whose upper lip grew larger through the ages, and in which the other variations of shape of leg and size of body were selected, until the result was an elephant. When we first hear such wonder-stories, we are skeptics, just as we were when we heard for the first time of X-rays or wireless. Ignorance has to be skeptical. But when we are familiar with photographs of our own bones and receive by wireless a message from our own family, we forget the first shock of skepticism. It is so with these series of adaptations. Many a modern scientist spent some days of boyish incredulity; now the marvel has become a commonplace in his day's work, like the in-

credible telephone or the utterly impossible gasoline engine.

Skepticism is removed only by familiarity. The sensible man will not accept mere logic, for he knows how often logic goes astray; nor can he accept the incredible because "they all say so." If any reader asks me how a bird's instinct for migrating was ever made by the gradual accumulation of variations in germ-cells, I give it up. So I should be at a loss if an Eskimo asked me how my voice could travel over a wire; for I don't know *how*. What I do know is that my voice is heard at the other end of a wire and that a bee's sting is the end of a series of variations. I know of some steps in the series: the first fossil insects were very crude; there was a long course of development before anything like a bee appeared, and it had no sting; the females had a pointed organ for laying eggs. That is worth thinking about. In a hive of bees the big males have no sting, but only those neuters which are undeveloped females. Here is the hint which biologists followed and which showed that a sting is a "modified ovipositor." We know that throughout the plant and animal kingdoms there are series of all sorts of variations for producing poison —from the prickle of a nettle to the astonishing feats of gall-wasps; a wasp is cousin to the bee, and it has developed a refined chemistry for the egg-laying process. So here is the same ever-repeated truth: a long graded series of stings and a long graded series of poisons. A zoologist can live and work by such knowledge; he can breathe if he has it, but he would stifle amid the nightmares of nature if he had no such help.

Even the stages in the development of an eye can be shown in a series of animals gathered under one show-case: (1) a mere spot sensitive to light, as in

certain animalcules; (2) an eye-spot that is covered by translucent skin and that has a special nerve; (3) a more developed spot, in which can be seen above the nerve a transparent jelly-like mass that acts as a lens to bring more light to the nerve; (4) an apparatus almost as crude, but which has a hard transparent covering and some coloring-matter at the end of the nerve; the slight steps of increasing complexity can be continued in a long and gradual scale up to the complex eye of a squid, which is so similar in appearance to the eye of a vertebrate.

Amuse yourself by trying to guess how a rattlesnake ever got its rattle. Then look in the old *Century Dictionary,* printed almost forty years ago: "The rattle represents the extreme of development of the horn or spine in which the tail of many other serpents ends." If you read on, you will catch a glimpse of the character of this animal: "Rattlesnakes are sluggish and inoffensive reptiles." No one could guess from that fact why a horn developed into a rattle, unless he knew that a great many animals, of all sorts, are so constructed as to advertise their deadly or offensive equipment. When we know about "many other serpents," and about a long series of skunks and nauseous butterflies that avoid fighting by advertising their bad qualities, then we can see the kind of variations that natural selection has worked with to build a rattle at the end of a serpent's tail.

It is the whole range in a graduated series, from slight beginning to intricate last stage, that obliges the scientist to accept evolution for a guide. He is not infatuated with the principle, has not the least affection for it, and would shake it off to-morrow if he could find anything better; but until there is a substitute, he will use it as a compass for exploring the jungle of adaptations.

Hundreds of keen students, noted ones and shrewd, have for sixty years been translating the history of life by the light of evolution. They have made some errors, have not agreed on some points, are still in the dark about others, and have quarreled about many particulars. But by their combined labors they have made out a fairly complete account of the general course of life on the globe. As to the beginning they know nothing, and do not pretend to know anything. They can only suppose that some original simple form of life, something simpler than a single cell, varied; that cellular structure developed; that several cells made up a colony; that the work of the colony was divided among different groups of cells, some securing food, some distributing it, some keeping off enemies, and some reproducing; that such groups varied continually in the direction of specializing, and thus became adapted to live as parts and not as independent wholes; that the whole groups became bodies, with organs to see and smell and move and reproduce. Here were species large and distinct enough to be preserved as fossils; from this point on, a part of the record is accurately preserved in the rocks.

Sixty years ago this explanation was a theory; thirty years ago it was so plain a truth that all the conservative works of reference adopted it as a matter of course; to-day the schoolboy knows that every form of life is descended from an earlier and less complicated form.

V. There Is No "Blind Chance" in Natural Selection

It is strange to think that the whole height and breadth of organic life was caused by variations in germ-cells. It is doubly strange if we speak

of these variations as due to "chance." For the common meaning of "chance" is mere luck, mere happen-so, without any particular cause. If I throw a quarter high in the air, making it twirl rapidly, there is no knowing whether the fall will be heads or tails. We say that there is an "even chance," and we never think of any cause for its falling either way up. If "chance variations" were of this head-or-tail sort, then all the intricate adaptations of animals would have been produced by a lot of luck.

If anybody says he believes that the world of life was made by luck, his statement sounds foolish. It doesn't sound sensible to assert that all the staggering marvels of an eye were formed by "mere chance." A man might just as well say that the Panama Canal happened to be dug, or that a magneto pulled itself together one fine day by a set of accidents. So if the theory of natural selection were based on mere luck, it would seem foolish even to a gambler.

In fact the word "chance" has sounded foolish to some people who are a great deal more logical than gamblers. John Burroughs, for example, was a highly intellectual man, an author of charming books; and he, though he loved and admired Darwin, was much offended at the idea that all adaptations were made by hit-or-miss. Other thoughtful men have felt that a doctrine of "blind chance" is very dreadful. And it would be dreadful. If Darwin had meant to teach such an idea, he would have been wild and wrong-headed.

But we know that he was one of the calmest and most careful of thinkers. Burroughs considered that he had a "master mind." So it is inconceivable that he blundered in such an elementary way. How, then, did Burroughs misunderstand him? By not paying attention to Darwin's plain emphatic explanation of

what is meant by "chance." Burroughs supposed that Darwin meant, as we do, unthinkingly, in common talk, *pure luck which has no cause.*

But Darwin used the word in an entirely different sense, and never dreamed that any critic would fail to take notice of his explanation. No critic ever would have overlooked it if he had known the meaning that is given in the next paragraph.

Darwin was using the language of science. The scientist knows that nothing can ever happen without a cause. He says that every flip of a coin is made by such an amount of power as will turn it over just so many times before it lights, and that there is no more luck about turning it over one hundred seventy-three times than there is about turning it over once. But we *don't know* how many times the force will turn it over; we *don't know* the cause of the heads or tails. The scientist says that no drop of water on a stormy ocean, no atom in a chromosome, can possibly be altered in any way except as the result of the absolute law of cause and effect. Though we say in every-day life that "I met him by chance," or that "his death was accidental," the scientist knows that the exact circumstances of every moment were perfectly accounted for by the preceding circumstances. It is impossible to know the causes, but they were there. All such cases, *of which we can not yet know the cause,* the scientist refers to as matters of "chance." Savages and crap-shooters and superstitious people can not understand this, and college men sometimes believe that things can happen without any cause; but the scientist knows that we can never escape from law and that there always is a cause.

Burroughs accuses Darwin of not knowing this. He says, "Darwin everywhere uses the word *chance* as opposed to law, or the sequence of cause and ef-

fect." The accusation is utterly untrue. In the *Origin of Species* the word is clearly defined at the beginning of Chapter V: "I have sometimes spoken as if variations were due to chance. This, of course, is a wholly incorrect expression, but it serves to acknowledge plainly our ignorance of the cause of each particular variation." That is exactly his use of the word—to mean that *we know nothing of the causes.* He is everywhere careful to indicate that any variation must have a cause, using such expressions as "the dimly understood *laws* of variation . . . variability is governed by many *unknown laws* . . . all these *causes* of change . . . variations, from whatever *cause* proceeding . . . as we do not see the *cause,* we invent laws! [said ironically] . . . differences given by nature; I mean by 'nature' only the action of many natural *laws.*"

Darwin seldom uses the word *chance*—for fear of the heedless critics. Once he says, "Mere chance, as we may call it." He found it convenient and proper to use the short word *chance* as an acknowledgment of ignorance, instead of explaining himself at length every few pages.

In another book Darwin illustrates his meaning by the pieces of stone at the base of a cliff: we speak of their various shapes as "accidental," though we know that every least fracture was made in strict accordance with law. From these stones to the remotest nebula in the heavens every shape in the universe has been produced by definite causes. Nothing happens without a cause. And it is so in plants and animals. The infinite variety of forms was produced by strictest law; for every item of structure in every individual there is a cause. When biology tries to trace the causes, it can take a certain number of steps—back to chromosomes or genes. Farther it has not been able to go.

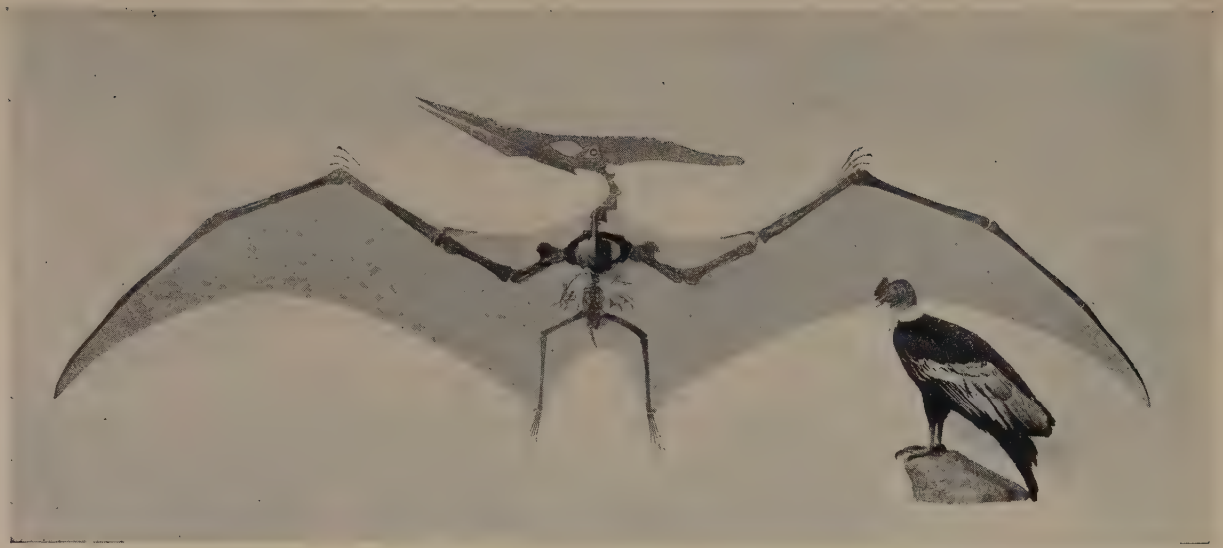
Science observes certain facts about the failure and survival of animals in their efforts to live, and it gives a name to those conditions. That name—"natural selection"—is not a power that works like a spirit or a man. It is not a creative force. It is a label that is put on a great body of knowledge, just as "the weather" is a convenient name for all those facts of temperature and water vapor and sun-spot electrons that cause sunny days and cyclones and snow drifts and fog and rain. The weather is a set of forces that we feel and see. Natural selection is a set of forces which determine that adapted plants and animals shall succeed in the struggle for existence.

VI. What Evolution Can Not Do

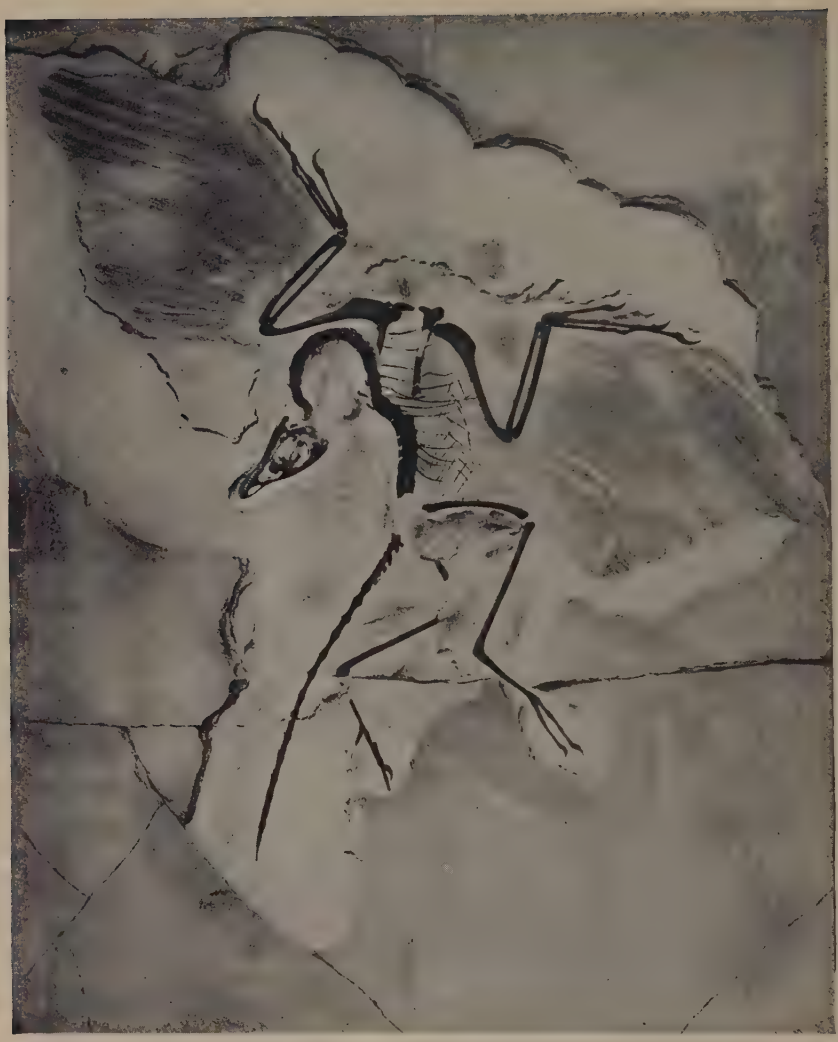
Evolution can not originate life. Children always inquire about first causes, expecting parents to tell them who made God. In much the same way we older people are prone to ask of evolution, "How did life begin?" And some scientists have speculated about the origin—whether the first cell traveled to us on a meteor, whether the first speck of protoplasm was made by a lucky aggregation of molecules in warm mud, etc. These are sheer guesses, scientific play. Nobody has the least knowledge of how life began. The evolution theory makes no pretense of explaining origins. "Biologists," says Woodruff, "are at the present time absolutely unable, and probably will be for all time unable, to obtain empirical evidence on any of the crucial questions relating to the origin of life on the earth."*

The idea that science is trying to reach origins makes some people dread it. They have an uneasy fear that perhaps it will remove the mysteries of life,

**Evolution of the Earth,* page 107.



One of the many kinds of large winged reptiles (a Pterodactyl), whose size is shown in comparison with a vulture.



One of the two known specimens of the earliest kind of bird that has yet been discovered—Archaeopteryx. It might have been called a reptile if some of its feathers had not been preserved.

will strip it bare of sentiment, and will reduce poetry and religion to a skeleton of facts. Any such uneasiness is a quaint misconception. Science has no such expectation. The deeper it investigates, the more it is involved in mystery; and it does not reach any explanation of the origin or nature of life. The true scientist is aware of the poverty of his little store of facts, for he knows much better than we how awesome and impenetrable are the ultimate secrets of the working of evolution. Huxley said that "in ultimate analysis everything is incomprehensible."

It does not cause progress. We all have a habit of thinking that evolution is an ascending scale of life, from a bottom somewhere in the slime up to a splendid horse or a noble dog. We have all our lives been accustomed to thinking of animals as "low" or "high" in the scale, and we naturally suppose that a development from bottom to top means moving onward and upward.

Mere science can detect only one case of what might be called progress—the advance from simpler forms to more complex ones. Even to this general course of evolution there are big exceptions: some species grow simpler in form after taking up the life of a parasite, and a great number of simple forms of life seem to have persisted through the whole of geologic times without progressing in complexity.

Otherwise science can not assert anything about progress. People reason about it and form opinions, but they can not agree on a definition of it. Science has not yet discovered any definition. Science simply tells us that the forms of life are constantly altering to adapt themselves to conditions, and it uses the words "better," "more fit," "improved." But it always refers to temporary adjustments in particular cases. It can never prove that any adaptation is

"progressive," but only that it is "another one." If a simple animal is well adjusted to its conditions, it might be said to have "progressed" farther than a complex organism that is failing to adjust itself; but that is a very doubtful proposition. "Progress" is a matter of emotion, like "love" or "patriotism"; and it is much less definable, and much more a matter of prejudice. With such debatable sentiments science can not deal. It puts the facts before us and leaves us free to thrash out our opinions. If a scientist wants ideas about the one increasing purpose that runs through the ages, he turns to poetry and religion.

It does not cause perfection. If we look back through the history of life, we find no examples of anything like perfection, or of any moving forward to it. The most admirable adaptation is only a temporary device, dependent on other temporary adjustments. When a reptile has so altered as to live in trees and to fly with feathered wings, it may appear "improved," and we perhaps expect a continued improvement in beauty and intelligence. But thousands of species of birds have perished—one of the most numerous and successful and beautiful was snuffed out during our lifetime. Its powers of flight and reproduction were no nearer to perfection than the highly successful reptile from which it descended. Its new powers meant new enemies, new perils; and no future adaptation of other birds will be permanent. Every adaptation of every animal is a way of succeeding fairly well, only well enough to keep the species alive for some thousands or millions of years, till conditions change and fresh variations are selected.

Science tells us to use our best judgment and not to fight about "progress toward perfection" until we are sure we know what we mean by those words.

VII. Natural Selection Begins with Variations

"Several writers," said Darwin in the last edition of his *Origin of Species*, "have misapprehended the term Natural Selection." At the close of this Part One, we should dwell upon his words. Darwin had defined his term with scrupulous care, and yet writers had misunderstood—not pupils in school nor business men nor hurrying editors, but professional critics of a scientific theory. No reader of this elementary chapter of a small book should be too confident that he will keep out of error.

For some reason even trained minds are likely to slip away from the one central and necessary fact. There seems to be some fatality in the central idea, for it always tends to slew around to one side and to hide itself. It played before the minds of men century after century and let them touch it; but it always slipped from their grasp. It played with Darwin, who groped for it and grabbed at it, and almost had it, and lost it. At length it grew over-confident. One day Darwin's mind made a lucky clutch and seized it firmly. He describes the affair thus in his *Autobiography*: "I can remember the very spot on the road, whilst I was in my carriage, when to my joy the solution occurred to me."

The trouble with all men up to that moment had been that they looked in the wrong direction. Darwin directed them to "modified offspring." An explanation of evolution must always begin with "modified"—that is, stated in modern terms, with variations that occur in germ-cells. We must look first at chromosomes.

The prime fact is that chromosomes are variable. The "chance" variations in them produce offspring that are not exactly like the parents. These varia-

tions are quickly sifted out and perish if they are unfavorable in the struggle for existence. But if they make an animal more fit—even in the very slightest degree—they are less likely to pass through the sieve, and so may survive. When they survive, there is a slight change in the adjustment to life conditions. And when the change becomes great enough for us to see, it is called an adaptation. That is the first—and the last—word in evolution.

PART TWO

The Evidences of Evolution

CHAPTER X

WHAT "EVIDENCES" ARE

An astronomer can prove absolutely to any one trained in mathematics that the planet Venus revolves between the earth and the sun, but it is doubtful whether any biologist will ever be able to give any similar proof of the theory of evolution. The biologist is convinced by numerous probabilities, each of which is strong, and all of which combined he finds irresistible. It is impossible for him to see how all the lines of evidence could draw together so perfectly toward one conclusion that is false. He would not be fully persuaded by any one indication, and might not be by any two; he is completely convinced by seven kinds which, quite independently, point to one central theory. It is the purpose of Chapters XII to XVIII to describe briefly these seven converging lines of evidence.

The nature of these probabilities may be illustrated from the study of history. Suppose that some skeptical reasoner should challenge the belief in the existence of King Alfred. If he had any skill and sense of humor, he could make a strong argument to show that Alfred is a mere "guess" of the historians; for the proofs that such a man actually wore a crown and built ships in Britain could be made to appear a flimsy thread—just a few old manuscripts, most of them written long after Alfred is said to have died. The ridicule could be easily made by any clownish essay writer. To prove that we have reliable knowledge of Alfred would be a long task; and when the

proof had been carefully built up, it could be laughed at once more as a string of "guesses." In like manner the history of the rocks may seem to an amateur a slight and tricky record, but the geologists who spend their lives with it are as sure of their knowledge as they are of the street on which they live.

Only the professional scholar can judge the evidences of chronicles or rocks. You and I would never give heed to a critic who tried to demolish history—*so long as all historians agree against him.* You and I pay no attention to a critic who rails against the germ theory of disease—so long as all bacteriologists agree against him. We do not believe in perpetual motion or the flatness of the earth or the effect of the moon on crops—so long as the whole body of specialists in the subject are agreed against such beliefs.

What is true of all lines of science holds for the Evolution Theory. If we could find that many reputable zoologists or botanists doubted the theory, we might suspend judgment or might disbelieve. If practically the whole body of scholars is united, we accept what they say. We must do so if we are normal and rational. And there is such unanimity among naturalists and laboratory workers to-day. To be sure, they have variant views as to just *how* the process has gone on; but they are all at one in believing that, as a matter of fact, by whatever mode, evolution has operated and that every present form of life developed from some previous and different form.

Hence Chapters XII to XVIII will be misunderstood if they are read as arguments. They are descriptions of the way the whole body of scientists look at nature. And the chapters will be misunderstood if they are read as attempts to prove anything, for proofs are far beyond my amateur powers or ambition. I prove nothing. I describe a great body of unanimous scientific conviction.

CHAPTER XI

THE EVIDENCE FROM THE RIVALRY OF SCIENTISTS

Before I present the seven lines of evidence, I should like to draw a picture of what scientific rivalry is. Though I have never seen any book that makes a point of this rivalry, it appears to me to be a kind of evidence that is more weighty for us amateurs than all the others.

It is often implied that scientists are leagued together in a kind of close corporation, that they have pooled their common interest and reputation, and that they are bound, as a kind of brotherhood, to uphold one another. This is a common form of superstition about leading bodies of men. I have, for instance, heard it seriously argued by a college graduate that "the Rockefeller money power put over the Prohibition Amendment and foisted it upon the American people." We often hear of "the politicians" or "the judges" or "the clergymen" or "Wall Street" as if they were well-drilled armies of men who acted by a concerted impulse against all comers and who would uphold one another at all costs and without reference to their individual opinions or ambitions.

However true this may be of some bodies of people, it has no semblance of truth when applied to scientists. Science has always been such a free-for-all arena that it has suffered by its dissensions. Every scientist is personally ambitious; he knows the shortcomings of other scientists; he is merciless in exposing

their errors; and he knows that if he himself publishes an error, it will be held up to scorn by keen critics. He dreads nothing so much as to make a mistake in judgment. He desires nothing so much as to make and publish a true observation that can not be successfully attacked. He must be perpetually alert, suspicious of false surmise, wary of every attractive novelty, diligent to avoid errors, keen to scent out where truth lies. If he is shrewd, he gains reputation and esteem. Nearly every scientist is poor; if he can publish a criticism that shows up some experimenter's error, he may gain fame, and perhaps money. If his own error is shown up, he may lose what is dearer than either money or fame—his self-confidence.

As a result, science is the opposite of a disciplined army of opinion; it is a thrashing-machine which pitilessly beats up the wheat that is fed to it, preserving the grains of truth and delivering the straw and chaff to a stack of rubbish. Every scientist tries to avoid the straw-stack.

An example of how the thrasher operates may be seen if we imagine the feelings of three men who were at Harvard when Darwin's *Origin of Species* appeared in 1859: Louis Agassiz, his son Alexander, and Asa Gray. Louis Agassiz was fifty-two years old. In his youth he had had the advantage of the best and most severe European training; when he was thirty-five, he had become the foremost authority on fishes; he soon after made himself the profoundest investigator of glacial activity; he was the most famous naturalist and the most inspiring teacher of natural science in America. His son Alexander was twenty-four years old, a brilliant young fellow, who had been pursuing graduate study in science for four years and had been appointed to the United States Coast Survey. Asa Gray was forty-nine. He had had no regular

academic training, yet such was his diligence and force of intellect that he had made himself the foremost botanist in America. How would three such men appraise this strange new book, with its strange new theory—this *Origin of Species?* The elder Agassiz was strongly prejudiced against the book by all his German training; yet in his lifetime he had seen, indeed had helped to cause, the overturning of the whole science of geology, and he knew that he must exercise a cautious judgment. If he pronounced against the new theory, and if his son and Gray were for it, and if the scientific world should accept it within ten years, then his triumphant career in the van of thought would be ingloriously ended, and he would be subject to chagrin and bickering in his declining years. His pride would not like to make a mistake where the son judged correctly. His pride would not like to be wrong where this crude, pioneerish American was right. Every strongest incentive of intellectual rivalry drove him to caution. His wits were matched against other men's wits. He was more eager to be right than an athlete to win a race.

He pronounced against the Evolution Theory, and strove against it for the remaining fourteen years of his life. Asa Gray pronounced in favor of it, and was its stoutest champion in America. As the years went by, Agassiz suffered the pain of seeing himself with an ever-dwindling minority, composed largely of older men. In the last year of his life he had to make the tragic confession to a fellow professor that his judgment about evolution had been wrong.* But Gray had the pleasure of seeing the ever-swelling majority grow on his side, finally including the younger Agassiz. He lived to see the Evolution Theory triumph in

*See *Science*, No. 1574, article by J. S. Kingsley.

the world of science, and to pity his European rival who had placed himself on the losing side.

Similar pictures could be drawn of episodes in every science. Ask any surgeon more than seventy years old about the theory that all infection in wounds is caused by micro-organisms. He will tell you of the conflict of opinion when he was a young man. Physicians of the old school scoffed at the new theory, which had never been heard of till after our Civil War. It had to run a long gamut of severe attack; no young practitioner wanted to subscribe to it if there was any danger that it would be disproved later; no older man wanted to argue against it if there was any likelihood that it was going to survive the test and be generally accepted. Professional pride made every physician anxious to decide correctly. The physicians were not in a league to uphold an idea or to denounce it; they all felt the spur of individual rivalry. When the germ-theory of contagious diseases came along, there was a similar situation. If any physician announced that he believed little plants caused tuberculosis and if the theory was later disproved, the physician's reputation would suffer severely. If he announced that he did not believe such rubbish and if the medical world soon afterward accepted the new theory, he would be considered ignorant and would lose prestige. So always in the scientific thrashing-machine: the man who can avoid the teeth of error is wheat; the man who opposes a new truth is chaff. It is this rivalry which gives us laymen assurance where the truth lies.

Whenever the result of an investigation is reported, every scientist is on the *qui vive* to judge it correctly; if he can detect any flaw in it, be sure he will pick it to pieces without mercy. During the last sixty years numberless men have thought they saw flaws in the Evolution Theory, and some account of

their attacks upon it is given in Part Three. But since 1890 no scientist of note has contended against the theory as a whole.

We are all apt to misunderstand the nature of argument about scientific truth. Most of us know only the sort of discussion that deals with opinions on large abstract questions—for example, of politics, religion, social problems, education. In such matters we have no positive demonstration, but can talk and talk; there is no possibility of sharply checking up by a set of facts and finding out whether we are right or wrong. Hence we seldom care to find out. Our emotions are enlisted. We are free to think and reason and declaim as long as we like. The more we reason, the more convinced we become that we are right. We cherish our opinions as a faith that is very dear to us, that we could not bear to lose. "The truth" is usually some mental state that is sacred to us and that we propose to defend with our lives and our sacred honor so long as we shall live.

To some extent and in many cases scientists are infected with this same human weakness: they may at times develop affection for a theory, and contend for it with ardor, but in general "the truth" is an entirely different matter for a scientist. Truth is for him a set of facts. He would no more oppose them than he would butt his head against rocks; he does not love them; he does not engage in battle for their sake. His only concern is to find where the facts are and not to collide with them. He has no more fondness for a theory than he has for a poor tool when a better one comes to his hand. If he has lived by a certain theory for fifty years, believing it entirely and guiding himself by it, and if to-morrow he perceives a better theory, he will discard the old one and take up the new one.

Here are two illustrations: (a) Ever since chemistry was a science the chemists have pooh-poohed at the idea of the transmutation of elements; but when transmutation was discovered in radio-active substances, they accepted the new truth as gladly as they discarded their old ignorance. (b) For nearly three centuries the physicists taught us that light was a set of waves in an invisible substance named "ether." This was not a pure invention; it represented in a very useful formula all the known facts about light. It served science well through those centuries, and no one could disprove its existence, though fame awaited any man who could dissipate it. Did the scientists dote on their dear old ether and long to preserve it against skeptical attack? Their hearts have never warmed to it. Already they are preparing to throw it overboard, because Einstein and Michelson are making its existence very doubtful.

They are a hard-hearted lot. They would throw evolution overboard next year if anybody could prove another more feasible explanation of the forms of plants and animals. They are no more devoted to evolution than they are to traffic congestion in a city. The minute that any one can show them a way to direct the streams of facts more conveniently, they will give him a cheer and accept his method. Every one of them knows this. He would rather discover the new solution than be president of the United States, for his fame would be commemorated on bronze tablets through all succeeding centuries of scientific history. The prize is supreme; the contest is open to all; every biologist would like to pull evolution down from its pedestal. But no one is yet in sight who can do the deed.

Such a super-scientist may arrive some day. This chapter is not a prophecy that evolution must

through all future time be the ultimate truth, but only an explanation of how it is still ultimate after sixty-five years of testing, and bids fair to remain so.

This chapter has frequently used the word "theory," and so it may seem to imply that the main business of science is to think up grand explanations of general principles. Such a notion would be the opposite of the truth. Most scientific work consists in observing and classifying facts, without any effort to make them conform to a theory. Hence it is unlike philosophy and theology and political speculation, where reason and logic are all-important. A scientist, in the last analysis, cares for nothing but facts. When a great mass of facts can be shown to be related as one general principle—for example, that every living organism had a parent—that principle is accepted as a handy device *for the time being.* It is temporary. It has no validity in itself. Scientists expect their theories to be altered or abandoned whenever any investigator can push his way into a new realm of facts. They are serenely indifferent to the fate of theories if only they can learn of new facts.

We laymen hardly know what such an attitude of mind is. Our habitual mental state is to believe something vigorously and want to fight for it, or to disbelieve something violently and want to contend against it. "Evolution!" I once heard an old lady exclaim, "why, I shouldn't believe it if I knew it was true!" She frankly confessed her state of mind, whereas most of us conceal it even from ourselves. That is the reason why most of us misconceive the whole way of thinking of a good scientist. We inevitably regard him as one of a party—as if he were a Methodist or a Republican or a Socialist—a person who has a creed to defend. He defends nothing. His only purpose is to keep on the right side of the facts,

to decide which observation of facts is right, and not to be worsted in the perpetual rivalry of wits where he is a competitor.

This rivalry is for the most part concerned, not with theories, but with small matters of fact. For example, a cave is discovered which contains some animal bones beneath a layer of gravel, and two feet down beneath them some human bones. Now what is the fact? Were the animal bones deposited in the cave after the human bones were covered up? If so, there is a chapter of prehistoric life to be read in one way; and the discoverer may so interpret the facts, and may publish his findings. Much depends upon his one bit of evidence. If he observes correctly, his name will be acclaimed in the scientific journals. But another scientist is suspicious. He carefully examines the cave to see what evidence there may be that the human bones were deposited artificially after the animal bones had been laid in place by a process of nature. If he can prove that the first observer was careless, he will capture the laurels. Every investigator, in the field or in a laboratory, is subject to that wholesome fear of being proved careless; if he dares to announce a verdict, he knows that he has invited inspection and courted hostile criticism. All the hundreds of specialists whose patient labors are mapping the rocks of earth know that any error will some day be detected and return to plague them. Every bacteriologist who reports what he thinks he has seen under his microscope is keenly aware that a dozen rivals will check his experiments and will pounce upon any error. It is thus that every shred of the Evolution Theory has been tested. It comes to us as from a blast furnace of hot rivalry, where false assumptions are purged away.

Nowhere is the rivalry more intense or useful than

in reading the bits of fossils. To me, in my ignorance, it is incredible that a single bone could furnish trustworthy evidence. I shouldn't know a human femur from the fibula of a baby dinosaur. I can't understand how it is safe to reconstruct from one bit of bone a whole skull and to declare how much brain-power it used to house. But the rivalry among paleontologists makes it safe to credit their reports. Long familiarity with all the details of all sorts of skeletons makes scholars sensitive to small clues. So a librarian of experience will tell you from one quick glance at the outside of a book that it was published in the United States about 1820; an orchestra leader will tell which one of twenty violins is flat; a blind man learns to detect unmistakably the most infinitesimal differences of sound and touch. Of course the students of fossils make errors, but if their competitors can find no flaw in a certain man's diagnosis, we may rest assured that it is fairly safe.

We non-scientists have small conception of how unremitting and exacting is the rivalry that tests out every announcement of a new experiment or observation. It is the best of evidence for the Evolution Theory.

CHAPTER XII

THE EVIDENCE FROM THE ROCKS

Imagine yourself on a Nebraska farm. The landscape is a series of gently rolling hills covered with rich grass, and not a rock is to be seen in any direction for a hundred miles. Here are two knolls different from anything in the region, composed entirely of gravel and rounded stones, some a foot in diameter. You are a thousand miles from the ocean, and yet in one of these small boulders is a perfect sea-shell, such as was never made in fresh water. How did the stones and the shell reach this position? This is a trifling example of the unanswerable questions that curious minds had always been putting when they observed the surface of the earth before 1700. In the Rocky Mountains there are beds of coral; there are vast beds of lava where no volcano is in sight; there are sea-shells near the top of the Alps; embedded in the rocks, hundreds of feet below the surface, there are impressions of leaves that are as precise and complete as if they had been made last week in the finest plaster-of-Paris; there are tracks of all sorts of animals, as legible as last night's hoof-prints to a hunter; there are skeletons, preserved with the minutest accuracy, of animals unlike anything that lives to-day. The rocks that bear these evidences of past life are of all kinds—some lying in level layers, some tilted, some in broken arches, some partially fused by heat. Inquisitive minds had wondered for twenty-five cen-

Said to be the most perfect dinosaur tracks ever discovered. They were found and photographed in Arizona, 1924, by Mr. Charles L. Bernheimer, who kindly allows me to use one of his prints. The animal had a foot 14 inches wide and took 42-inch steps.

"Tyrannosaurus rex," or king of reptile tyrants, probably ruled more than seventy million years ago. His skeleton in the American Museum, 18 feet tall, was the basis for the work of the artist who advertised "The Lost World," a sensational motion picture.

turies whether these old manuscripts of nature could ever be deciphered—written as they are in an unknown language on broken and jumbled leaves of rock.

The ancient Greeks reasoned quite naturally: "If there are sea-shells in the mountains, then the sea must at one time have been where the mountains now are." That was a very sensible supposition. It would have been followed up and proved bit by bit long before 1700 if the theologians had not been afraid that every such effort at explanation was an attack on the Bible. It was dangerous to teach that the earth was round, because the Bible said it was flat; it was impious to believe that the earth moved, because the Bible said it stood fast; it was blasphemy to guess that the hills and the ocean had changed places in the course of ages, because the Bible declared that the hills were everlasting and that bounds had been set for the ocean; to reason about the great age of mountains was atheism, because the Bible taught that the world was less than six thousand years old. Nearly all the devout people in Christendom honestly feared that any investigation of the earth's surface was perilous to the spiritual welfare of the human race. As late as the American Revolution there were eminent divines who denounced the idea that there was ever an ocean where the White Mountains now are. If Noah's flood would serve to explain the rocks, well and good; but any reasoning about another flood more than six thousand years ago was an attack upon religion.

All this is hard for us to realize in our day; and yet we still hear echoes of this dread of science. Some old-fashioned people are still afraid that the evidence from the rocks may damage the Bible. It is comical, though it is disheartening, to see that the human mind could ever have had faith in a Bible about which it

was so timid, or could ever have been so superstitious as to think that the sacred Testaments were a volume of science. The great majority of the men who laid the foundations of geology were believers in the spiritual truths of the Bible and the real defenders of it; they insisted that it should not be desecrated by being dragged into the scientific arena, but that it should be elevated above and beyond science. It is still necessary to state this fact in every popular explanation of the record of the rocks, though it has long been a truism and will probably not have to be rehearsed many years more.

Under this fear of seeming to dispute the Bible every investigator labored in the eighteenth century. I will give only one illustration of how they were hampered, and then sketch briefly the history of the reading of the record in the rocks.

I once saw some tracks in the surface of a newly laid cement road. Any man in his senses could have known that they were not made by an elephant or an ostrich or a lizard; even an ignorant fellow like me could know to a certainty that they were not formed by any animal with a hoof, nor by a rabbit, nor a squirrel, nor by a cat, nor by any dog less than a foot long. A keen trapper would have described, beyond any shadow of doubt, just what kind of dog made the tracks. If, now, I could have covered those few square feet of road, so that no sunshine or moisture or frost or chemical could disfigure the tracks, and if I could thus have preserved them completely for a year, another trapper could have known exactly what the first one did about the cause of the tracks; and ten years later, and fifty, and a hundred it would have been just as certain how the tracks were made. After a thousand years perhaps that kind of dog would be extinct, but a man in that age would recognize that the

tracks had been made by an animal nearly like some variety that he knew. After ten thousand years the record would be unmistakable, and after a hundred thousand, and after a million; those half-dozen footprints would be evidence that in some minute of bygone ages some animal had set its feet in some soft substance that hardened and preserved the outline of its tracks. Even more unmistakable are the shells and skeletons that have been preserved by nature in a similar way. Yet the men who found fossils in the eighteenth century were asked to believe that the shells and bones were not real, but were "sports of nature," tricky likenesses—perhaps placed there by the devil to lure men away from religion. It is likely that if any American professor had taught in 1750 that fossils were ancient remnants of real life, the president of the college would have asked him to resign.

But by that time the collectors of Europe had piled up and classified such stores of fossils that it became impossible for them to believe that the specimens were sports of nature. They had every appearance of being just as real as a feather or a skeleton found in the woods. Here and there through the centuries observant men had dared to speak of fossils as proofs that the ocean had been where mountains now are—for example, the great artist and scientist da Vinci wrote in his note-books about 1500 a lucid account of fossils; and an Englishman had published before 1700 a book of similar reasoning about them. Contributions of this sort continued all over Europe throughout the eighteenth century, so that by 1800 the world had pretty generally accepted the fact that fossils were made more than six thousand years ago and were not deposited by Noah's flood.

All through the eighteenth century there was also in all countries a diligent study of the rocks them-

selves. It began to be clear, as workers from different fields compared notes and showed up one another's errors, that there had been a history of the earth's surface, that rocks varied in age, and that, in a general way, the youngest were on top. Many speculations were put forward as to how rocks were made, how they could be heaved thousands of feet above the sea, and what epochs of rock-making could be figured out from the jumble of evidences. At the time of the American Revolution the generally accepted theory was that the whole earth must once have been covered by the ocean, that the different sets of rocks were "deposited" by the ocean (somewhat as salt is when brine evaporates), and that three principal classes could be distinguished: the "primary," or oldest, which showed signs of having been fused by heat; the "secondary," or level strata on top of these; the "tertiary," or loose sand and soil. It was taken for granted—as most of the population of the United States still suppose—that by studying the rocks men could find out which kind were early and which kind were late. It was, for example, assumed that lava was more recent even than the "tertiary" gravel, because men had seen it poured out on top of the soil.

All such efforts to construct a history of the earth's crust would have come to nothing. Lava flows have been found underneath the folded "primary" rocks; level "secondary" strata have been found under the "primary." There is proof that in one place limestone is more ancient than sandstone, and that in another place sandstone is more ancient than limestone. We now know that different sorts of rocks have been made at many periods of the earth's changes. No history of them, as rocks, could ever have been discovered.

The clue to the history proved to be the fossils

embedded in the rocks. More than two centuries ago several Italian scholars published explanations of this general idea. They argued that rocks were probably formed in the ocean by the depositing of mud brought by rivers; that successive layers of this clay or sand or gravel were hardened into successive strata of rock; that certain kinds of animals were living when each stratum was formed and that these were preserved in their respective layers; and that, therefore, whenever you found similar fossils in two sets of rocks at different parts of the earth, you had rocks of about the same age. We must sympathize with the men of that time who considered this theory fanciful. It had to stand the hardest kind of attacks for a hundred and fifty years, and it would not have survived if it had ever once been at fault. It has never failed to stand the test. Every decade has brought fresh evidence that it is the only key to the hieroglyphics of geology.

Late in the eighteenth century the head of a French monastery occupied himself with the study of the shells in some limestone cliffs near the Rhone River, just as an Austrian monk in the next century studied his peas with scientific accuracy; and both became contributors to the Evolution Theory. The French abbot found five distinct sets of shells in the successive layers of limestone, and in the lowest layer were no shells of species that then lived in the world; from here to the top the shells grew increasingly to resemble modern types.

In 1815 an English surveyor, William Smith, who had for many years systematically observed fossils over large areas of England, published the maps in which he had classified the rocks according to the ancient plants and animals embedded in them. So thoroughly and shrewdly did he do his work that no

serious flaw was ever found in it, and it became the starting point of all true histories of rock that have been made since his day. In proportion as more and more old species are discovered and as wider and wider areas of land are explored, the truth of the fossil history becomes more evident. The more it is put to the test, the stronger it grows. A modern geologist could no more expect it to be overturned than you and I can distrust our theory that winter will come again after next summer. Our faith in the coming seasons may be merely a theory, but we have confidence in it.

Throughout the nineteenth century the classifiers of fossils in Europe increased in numbers and knowledge and skill. Many wrong conjectures were made, many errors of observation; but the rivalry of science was always grinding down the mistakes and preserving the facts. Some wild theories were advanced by men who could not accept the crude ideas of evolution current before Darwin's time. One brilliant Frenchman, for example, inferred that at many times in the earth's history there had been a complete destruction of all plants and animals and that each time a new and more advanced series sprang suddenly and miraculously into existence. His guesses were disproved. From all sides, from students of all sorts of fossils in the new world and the old, came an increasing mass of evidence that there had been only one series of life and that it had developed continuously. There was increasing evidence that no great breaks or "cataclysms" had ever occurred in the earth's history. And as the outline of the history took clearer shape, it was seen to stretch farther and farther back into remote times. In 1778, when Buffon estimated that all life had lasted about fifteen thousand years, he was considered extravagant; but fifty years later a

hundred times that many years would have been thought a very low limit.

Though the knowledge of fossils continued to grow in fulness, it could not be assorted into any orderly arrangement, because scientists did not know what the succession of types of fossils meant. There were the shells and bones, as plain as any sign-board, but they were in a cipher code. The greatest of the early scholars, Cuvier, published a vast lot of information between 1800 and 1830: he saw that elephants unlike any now living had once roamed in jungles where Paris stands; he saw the hippopotami and rhinoceroses and crocodiles that used to walk in France; he studied countless fishes and birds and serpents that no longer live. But what of it? How could these signs in the tiers of rock be decoded? Other men found, in widely separated places, very precise arrangements of coiled shells; they were graded from the plain types at the bottom, through fluted and ornamented types, to a less ornamented type, and finally to a plain but noticeably different type at the top. In England and Italy and Germany were the same messages. They stared naturalists in the face, grouped as accurately as if they had been so many sizes of gravel-stones run through successive sieves; and nobody knew the meaning of this arrangement.

Yet even Cuvier agreed that one fact was obvious: "there has been an upward development in the animal forms inhabiting the globe." No evidence ever appeared on the other side. As new series of fossil plants and animals were reported from America and Russia and India, they always showed the same kind of arrangement: from the forms in the lowest stratum there was always development of some sort toward the forms in the highest stratum. No one discovered any arrangement of the opposite kind, or even of a somewhat different order.

By 1840 there had been reports from many parts of South America, from Australia, and from parts of Africa; the Geological Society of London and the Geological Survey of New York had been established. Everywhere men were scrutinizing the rocks and fossils, recording what they saw in their part of the world, reading of what other men had seen in their countries. Murchison had gone below the coal beds in Wales and had found there the same kind of evidence that had been found above—that is, distinct layers of rock, each of which bore its own special assortment of fossils. He named these newly discovered formations after the ancient inhabitants of Wales, the "Silurian," and confidently predicted that whenever the Americans could get a glimpse of rocks lower than their coal beds, they would find there the same Silurian fossils, in the same order. And his prophecy had been fulfilled. In another part of Wales the Reverend Adam Sedgwick, an adept in unraveling rock mysteries, discovered a still older formation, with its distinguishing kinds of fossils; and this he named, after the ancient Wales, "Cambrian."

By 1850 dozens more of inquisitive geologists had learned so many more details of these ancient records that they could tell the difference between the earlier and the later layers of each group. So intimate became their knowledge of the different shells in the layers that if they had received from another part of the world a certain sort of hinge on a shell of a certain size, they would have known instantly whether it was of the Cambrian or the Silurian age; they could have told what other shells would be found alongside it, that certain other shells might be above this layer, *but could not be below it.*

No exception was ever found to this *order* of the fossils. Of course there were all manner of complica-

tions and apparent discrepancies. Many kinds of animal and plant remains were found almost unchanged through many ages of rocks, so that they would not serve as indexes to periods. There had to be wide study to learn what shells were indexes, and what the combinations of fossils signified. But in the main the fossil clues were found to be invariable and

Diagram, from Goodrich's *Living Organisms*, to illustrate the growth and death of species. The extinct ancestors in the fossil record are shown by dotted lines; species still living are shown in black.

unfailing. The coiled "ammonite" shells became an alphabet of the earth's history, as unmistakable as if they were the letters M E S O Z O I C. In each decade since 1850 the knowledge has broadened and deepened, and grown in detail. If any single exception to the *order* of the fossil record had ever appeared, it would have blighted the whole science of geology—

just as surely as the proof that there was once a king of the United States would upset all our school histories. And fame has always awaited the geologist who could prove such an upset of the fossil record. But no man has been able to discover the exception. A geologist no more questions the story of the rocks than a boy who reads about yesterday's league baseball thinks the games are a myth.

Yet the geologists of 1859 were in the dark. By their flash-lights here and there they saw the unmistakable record; they pieced it together; they knew it as surely as they knew that they had eyes, but they knew it as a patchwork of incomprehensible fragments. The greatest of them all during a whole generation, Sir Charles Lyell, had no faith that there was any general progression of forms from the earliest times to the latest. His clear-headed judgment on all the facts that men had piled up was simply this: "We have not proved any progression of forms, from simple ones to complicated ones, through succeeding ages. We may yet discover the bones of a mastodon among the Cambrian shells."

Imagine what the Evolution Theory would have meant to you if you had been Sir Charles Lyell in 1859. "If Darwin is right," you would have said, "then his idea is like the glint of sunshine to a person who has been lost in the mazes of a cavern; if I follow his theory, I shall be in the daylight henceforth. But if it is wrong, it will be only the flicker of a candle in the hands of another man as lost as I am. Is Darwin right or wrong?" That was the question that Lyell faced when, early in September, he unwrapped a bundle of some of the page proofs of the *Origin of Species* that had been sent by a London publisher. And imagine how you would have felt if you had been Darwin. After twenty-five years of constant labor and

thought you have put your conclusions into the thrashing-machine. Are they wheat or chaff? Will this greatest student of rocks and fossils accept my theory? He is sixty-two years old; can he, at such an age, alter his whole view of the nature of life?

"Do not be in a hurry in committing yourself," wrote Darwin to Lyell on September second. "Remember that your verdict will probably have more influence than my book at present; in the future I can not doubt about the admittance of my views, and our posterity will marvel about the current belief." On the twentieth he wrote again: "As I regard your verdict as far more important than that of any other dozen men, I am naturally very anxious about it." On October fifteenth he wrote to Hooker, the foremost botanist of England: "Lyell seems staggered by the lengths to which I go. . . . I entertain hopes that he will be converted, or perverted, as he calls it." On October twenty-third, again to Hooker: "I had not inferred from Lyell's letters that he had come so much round. I remember thinking, above a year ago, that if ever I lived to see Lyell, yourself, and Huxley come round, I should feel that the subject is safe."

He had only a month to wait. Then came a note from Hooker which spoke of "your glorious book" which will be "very successful" and of how "Lyell is perfectly enchanted and is gloating over it." Lyell had already determined to admit the new theory to a revision of his *Geology,* and Darwin wrote to him: "To have maintained, in the position of a master, one side of a question for thirty years, and then deliberately give it up, is a fact to which the records of science offer no parallel. I rejoice profoundly." Huxley wrote a favorable review and girded on the whole armor of his intellect to fight the good fight for evolution—or, as he put it on November twenty-third, "I am sharpening up my beak and claws."

The whole meaning of the Evolution Theory to geology was thus summarized by a correspondent who wrote on the same day as Hooker: "How could Sir Charles Lyell, for thirty years, think on the subject of species *and their succession,* and yet constantly look down the wrong road!" Ever since 1860 geologists have been able to look down the right road. Read any text-book or encyclopedia article, and you will find testimony similar to this from the *Britannica*: "*The Origin of Species* produced an extraordinary revolution in geological opinion. The older schools of thought rapidly died out, and evolution became the recognized creed of geologists all over the world." In the light of the knowledge of evolution they have read a record of vast eras, a record which is all consistent, intelligible, indisputable. They could no more continue their researches without evolution than a historian could read if you took away his theory that lines of print begin at the left-hand side of the page. Hundreds of geologists are mapping rocks in all quarters of the globe. If they assume that all species of animals developed from previous species, they can make sense of the fossil record; if they should assume any other explanation, all geology would become a heap of meaningless curiosities.

No achievement of the human mind is more creditable than the building up of a connected narrative of the changes in the earth's crust. I offer a brief sketch of the result as an example of what the Evolution Theory produced when it was applied to this stupendous riddle and was found to be an unfailing guide. The first four paragraphs have nothing to do with evolution and do not tell of a proved theory, but I include them in order to furnish a beginning of the story. It is based on *The Origin of the Earth* (University of Chicago Press), by Professor T. C.

Chamberlin, a little book which is quoted with respect in recent scientific works.

A billion years ago or more, as one of the stars, our sun, was soaring along calmly, another star came near. This meeting was quite in the ordinary course of things, for by the law of chances there must be now and then such encounters in the wide spaces of the heavens. It would appear that the star was larger than our sun and that its course happened to swing it very near the sun, though not producing a collision, and then to speed it away. Perhaps the meeting was only for a few days, or a part of a day. The bulk of the star almost disrupted the sun, for its attraction was so great that the matter of the sun began to stream out toward it; and if it had come a little nearer, it would have drawn the whole sun to itself. So adjusted did its course happen to be that during its approach it caused four bolts of sun-stuff to shoot forth, four more as it receded, and then sped away without doing more damage. (Such results are not an astronomer's dream; cold figures show that just these effects would be produced by a meeting of a kind very likely to occur.)

In such a sudden and spectacular way was the sun set upon and almost annihilated. Yet it had not been much diminished—no more than if you should draw off from a molten mass the size of a baseball enough material to make a small marble. The wreckage of the encounter was strewn about the sun in eight irregular bunches of molten minerals and gases, which rapidly cooled, spread out as they were in a temperature of four hundred fifty degrees below zero. They had darted toward the star, bending after it as it raced away, but it had been too fast for them. So they were left within the range of the sun's attraction, yet

unable to return to their warm home. There was nothing they could do but continue to whirl in orbits around the sun. And there they have whirled ever since—eight planets, of which the third from the sun is our earth.

Each of these shapeless baby planets began to set itself in order. Its core rounded into a globe, to which the outlying fragments were attracted. As it went along its orbit, it was continually drawing to itself the wreckage that lay there. As the centuries went by it continued to mop up its path, to gather the debris to itself, and so to increase in size. Countless tiny planets, the "planetesimals," pursuing their private courses around the sun, were daily drawn into the major planets.

That is the picture that the "Planetesimal Hypothesis" offers us of the origin of the earth. It is a conjecture so carefully calculated that it seems highly probable. According to this theory there was a period early in the earth's infancy when it was not half so large as now, cooled from its original heat, already surrounded by some air, and having on its surface the beginnings of an ocean. It grew gradually and uniformly, as cool at the surface as it is now, by picking up the bits of sun-stuff that it encountered. Since that earliest and briefest period of infancy it has never been molten, never even hot on the surface, never the scene of violent changes, never more disturbed by volcanos and earthquakes than it is at present. The history of our earth has been a placid one.

"Gradually, calmly, uniformly" is what the history of the rocks is forever repeating to us. Most of us have been familiar with the contrary idea. "There were tremendous doings here once," I have heard passengers remark as they look at the Rocky Mountains from a train; they think of the past as a violent

The Diatryma, from Wyoming, has to be called a bird, though it was unlike any ancient or modern bird and could not fly. It was a queer, unsuccessful twig of the tree of life.

These rhinoceros-like Titanotheres developed in Wyoming. Each skull is known, by the stratum in which it was found, to be older than the one placed above it, to the right.

volcanic age, which was in contrast to our slow and peaceful era. We are familiar with the description of the earth as a fiery mass that cooled enough for a crust to form, though it was still molten inside, that finally cooled enough after an age of frightful disorder to allow coal to form, that continued to cool and to thin its atmosphere until some animals could live on it, that cooled to an ice age, that will grow colder still, and that will at length freeze into a dead mass like the moon. Recent geology knows of no such process. Geology tells us that as it was in the beginning it is now and, so far as can be foreseen, ever will be. No making of mountains in the past was ever much more spectacular than what is going on now right before our eyes. There have been ice-ages as far back as any record can be read in the rocks. Where the oceans and continents are now, there they have always been. The land masses have come and gone and come again, but always in the same general locations. Since its romantic beginning the earth has had a quiet history, almost monotonous.

The modern geologist pictures the earth as made of a dense core, rich in heavy metals, kept hot by the work of its own gravity and by chemical action, and covered with a crust of lighter rock some fifty miles thick. Some form of adjustment is always taking place within this crust—not that it is "wrinkling like the skin of a drying apple," but that parts of it are contracting and expanding as they adjust themselves to the shifting loads on the surface. Some heaving appears to lift up masses of stratified rock—very gradually, through long ages—on certain fixed lines of adjustment in the crust, and so to make mountain ranges. Then may come a compression which slides rocks for fifty or even a hundred miles from their first location, and tilts them as we see them in the

Alleghanies or the Alps. Recently geologists have learned that the material under a mountain chain is lighter than the material which underlies the regions on either side of the chain: the mountains seem to be counterpoised by denser portions of crust. In the beginning there were certain lines of adjustment—about where the greatest mountain chains now are—and there the mountains have usually been made. There were certain regions of depression—and there the deep oceans have always been. The changes in the earth's surface have been a routine, a slow pulsing in certain regions.

Though the alterations seem large to us, they are slight compared with the total bulk of the earth. The top of the tallest mountain is only six miles above sea level, a height which would be represented on a twelve-inch globe by no more than the thickness of a sheet of note-paper.

As soon as a mountain range begins to rise, it is attacked by the water—worn down by friction, chipped by ice, decomposed chemically. Though it rises ever so high and is ever so hard, though the action of water seems ever so slight, the water will conquer in the end; for water has as many millions of years as it needs to complete its destructive work. Slowly it carries away the pulverized rock, carries it as silt to the sea, and deposits it. As the thousands of years pass, the top of the mountain is being laid down in the bottom of the ocean. There it is subject to great pressure from later deposits, and to a cementing process. It is converted back into rock. Layer is formed upon layer. Thus an increasing burden is laid upon the shifty foundation of semi-fluid rock several miles below. Some time the strain will become too great to be borne, and then this new-made rocky bottom of the sea will be slowly crumpled

and lifted, perhaps only a fraction of an inch a year, into a new mountain chain—to be again worn down, and again raised up.

Suppose that half a billion years is a correct estimate* of the time since the first animal left a record of itself in the rocks. Suppose that an angel had been commissioned to take a photograph of the North American continent, as it appeared at that time, from an altitude of several thousand miles, where a lens could command a view of the whole expanse. Suppose that every five thousand years thereafter the angel had taken another view of the same part of the earth from the same point. If the one hundred thousand negatives thus far taken could be put together in a single reel, they could be shown on a screen in an hour. Watching such a picture would be heaven for a geologist. What would he see?

Imagine that a map of North America is traced in dotted lines on the screen, so that as we see the views of the ancient land masses we can tell where they were. Understand that the reel which we are to see begins when half of the rock-forming history of the earth had already passed. Of all the previous half-billion years of the continual heaving up and wearing down of land we can have small knowledge. But we do know that before our motion picture began thirty-two miles of sedimentary rock had been laid down in the ocean and raised above it, and that during the

*Barrell's estimate, on a uranium basis, of the time since lower Cambrian is seven hundred million years, and Schuchert thinks "this is excessive by fifty per cent." (*The Evolution of the Earth*, Yale University Press, 1918.) The figures will seem excessive to most readers, because they are five times as great as those given in most recent books of reference; if they are too high, they will be the first estimate that ever erred in that way. See the 1922 *Britannica*, article *Palaeontology*. The data for the sketch of the configurations of North America since Cambrian time are in Grabau's *Textbook of Geology, Part II*.

time of the picture only twenty-one miles of rock were made.

As a prelude to the main reel comes a one-minute picture which gives two glimpses of the era before the Cambrian and indicates that we are plunging into the middle of the total history. It is a close-up of the Great Lakes region. A sheet of ice stretches down from the north to the American border, its ragged southern edge quivering back and forth; after ten seconds we can see that it is retreating, as the tide goes out with a series of advances that are farther and farther down the beach. The ice disappears to the north. There is a heaving up of land. Then near where Lake Superior now is a volcano pours out smoke; another appears to the north of Lake Huron; great sheets of lava, hundreds of feet thick, cover wide areas. In them, if we could but see, are the copper and silver that are now being mined in those regions.

The picture closes and there is an interval. Then the main reel begins with some blocks of land that we should never recognize as our continent if the dotted lines of the map did not guide us. There are three of them: the largest stretches from north of the Hudson Bay region, tapering to a point in southern Mexico; the second is at the left, a block corresponding to Alaska and stretching southeast where the Canadian Rockies now are; at the bottom is the third block, where the West Indies now are, stretching in a slender northeasterly neck across to England. Long arms of the sea separate the two smaller land masses from the large continental one.

You watch the lower end of the great central continent slowly disappear, and the channels on either side of it widen slightly; the sea encroaches* some-

*So it appears on the screen and so the geologists speak of it. What actually happened, of course, was that the land sank.

what on all the land for two minutes. Then for two minutes you observe that the sea is retreating and the land extending. During the following two minutes the changes are greater, for the whole southern third of the central continent is eaten away, and the other two blocks alter their shapes, becoming somewhat smaller in area. You do not find this entertaining. In seven minutes of the monotony you do not see as much change as an animated cartoon ought to show in three seconds. You shift in your seat and wonder whether anything worth while is going to happen during the next seven minutes. The learned lecturer tells you that you have now seen the whole of the great Cambrian period and are well into the still greater Ordovician. You are not thrilled.

Still there is more doing on the screen. You see the central continent creep farther and farther south, widening as it goes, filling the arms of the ocean on the east and west, taking on an almost familiar appearance: you can see a Gulf of California, a San Francisco Bay, a Puget Sound, and a Mississippi River. But the Gulf of Mexico opens toward the southwest, and a river twice as long as that ancient Mississippi runs from the state of Washington through Oregon and Nevada and Arizona. Now the ocean begins again to eat the land away, opening up the arms on either side of the continent and washing out a large gulf through Illinois and on through Iowa and Nebraska. At length it cuts clear across to the Pacific Coast, and runs a wide arm north through Wyoming to the Arctic Ocean. The continent becomes a set of islands. So for a minute it remains. Then the land begins to grow, until a fairly respectable continent emerges, stretching unbroken from northern Alaska to a tapering point in southern Mexico. "The close of the Ordovician," the lecturer an-

nounces; "now note how the sea begins to wear down the continent and carve a north-and-south channel through it at the opening of the Silurian. The Silurian will last four minutes."

As a movie, this sort of display on a screen would not draw crowded houses. Yet any one with imagination has spent an extraordinary quarter-hour, watching the rocks come and go with the slow lapse of millions upon millions of years. Every second of this picture represents one hundred forty thousand years —ten times as long as the whole recorded history of man. A minute of these motions on the screen is longer than the mind can conceive—more than eight million years. Our quarter of an hour has meant fifteen times those eight million years, and yet that whole inconceivable extent of periods is but one chapter in the whole volume of the ages of the world.

We have seen on the screen nothing but the coming and going of land. What about life? When the reel opened, life was already far advanced; there were beautiful scallop shells and jelly-fish and complicated crab-like animals. For aught we know these forms had been developing from simple one-celled animals during a whole half-billion of years. In the quarter of the motion-picture that we have seen the corals developed, and the chambered nautilus, and a kind of fish. So much advance to show in one hundred thirty million years!

Somehow, when we realize what this picture means, the remaining minutes of Silurian time will not utterly bore us. It represents twenty-five million years, during which the ocean three times reduces the size of our continent, and three times is slowly driven back by the rivers that pile sediment along the shore. There is a fascination in seeing this portion of the earth's crust pulsing back and forth, never entirely

consumed in the waters of ocean, always returning to that shape that tapers off at the south in the familiar Mexican outline, always showing some sort of Alaskan and Canadian and West Indian land, always showing a tendency to gulfs where gulfs are now. And there should be wonder in our hearts as we recall that this history was never revealed to geologists by an angel. No, they had to pack burros and wield hammers and draw maps and study specimens and compare notes and show up each other's mistakes for a century before they could piece together the fragments that we are seeing by the grace of heaven. "If in this shale there is such a species of fish, and if this sandstone underneath it is of so coarse a texture, then"—by comparing thousands of such inferences they slowly built up the knowledge of where the ocean was at different periods. Fishes are not adapted to desert life, and ferns never grew in the sea; each fossil of such an adaptation as a fish or a fern shows what the environment must have been for that form of life at that time. There is no more mystery in reading the geological record than there is in reasoning that an old oriole's nest was made by an oriole. All that is required is infinite care and patience, driven by curiosity.

The records of the Silurian, and of the Devonian that occupies the next four minutes, show only one marked advance in organic life: certain fishes developed lungs, and so could live on the land. Plants also adapted themselves for living on land. At the times when the ocean was driven back there were likely to be certain bays that were filled across the mouth; the water-dwelling plants and animals that were thus cut off from the ocean would perish as the water grew brackish and finally evaporated. But if any organism varied in such a way that water became

less and less necessary to it, and if these variations were inherited and increased, that species could in time become adapted to live altogether on land. It would survive, while all the others would become extinct. Such development came about some time during the last two periods that we have seen on the screen. It was momentous. Life then escaped from the sea and began its career on land.

Now for eleven minutes you may watch the sea eat out the top of North America in a great gulf that reaches down to Mississippi and east into Pennsylvania, and then retreat again. A close-up of this new land left by the retreating sea shows that it is covered with a strange forest, composed of forms like our modern ferns and horse-tails and ground pine, but magnified to large trees. It is a riotous growth of the plants that have learned to live on land and that have waxed gigantic in the rich, new, low, swampy soil. As the trees die, the trunks and leaves form a kind of peat-bog that is transformed and compressed into coal. Insects swarm in the forest—some early elementary kinds of bugs and beetles, cockroaches, and especially darning-needles, some of them thirty inches long. There is a reptile that reaches a length of eight feet.

The semi-tropical growth fades away. The land rises, and the climate becomes cold. Those animals that have been well adapted to the warm moist conditions are in hard case to survive. Many must perish. Lucky are the animals that now have variations which fit them somewhat better for the struggle with a harsh environment. This five-minute period* causes rapid evolution of new types. A chart of the animals through the ages widens out suddenly at this section into many kinds of short-legged, lizard-like reptiles.

*The Permian.

During the thirty-six minutes of this picture that we have seen—and during a whole previous reel that geologists can never see—life has been developing; and has progressed only as far as a big lizard. It is the early stages of any development that require time.

From now on* the changes of the land will be quicker and seem more significant. During the last six minutes it comes back to almost its present shape, and remains so. In the last quarter of a minute of the performance you see a spectacular ice-sheet come down jerkily almost to the Ohio and Platte Rivers, and then retire. It was this that left the hills of pebbles on the Nebraska farm. And man in this picture? He was on the globe during the last second or two; civilized man has been here a tenth of a second.

A few views of the animals during those last twenty-four minutes would furnish entertainment.† For fourteen minutes we could watch the reptiles increase in size, till some achieve a length of a hundred feet; and some grow heavier than four big elephants. They walk principally on their massive hind legs, which are midway between the long neck and the tapering end of the long tail. There are many other types of these "dinosaurs," and all varieties of other sorts of large and small, smooth or horned, lizard-like animals. It is the age of reptiles. From one species of these the birds developed, from another the earliest mammals. Other reptiles remained reptiles, and are with us today—crocodiles and horned toads and turtles and snakes. And all the other reptiles? They died out.

There could be a picture of the progress, during the last six minutes of the reel, of a little animal only a foot high that walked on five toes. Its four side

*That is, after the Paleozoic.

†O. H. Ditmars has made, and shown to enthusiastic college audiences, a moving picture of animal evolution.

toes grew smaller; its middle toe grew longer and longer; it increased in size until it was five feet tall, and became the modern horse. The paleontologist has been able to reconstruct other histories, quite as remarkable, of insignificant animals that developed during these same periods into the camel and the elephant. The stages of their growth are in the rocks, as surely labeled and dated by accompanying fossils as if they were classified for us in a museum. Yes, they are more reliably recorded; for naturalists make mistakes, but nature never does.

When any man has learned the alphabet of the fossils and is familiar with its grammar and idiom, he reads with assurance the history that has been preserved in the volumes of stone. It is written in the language of the Evolution Theory—more consistent and indubitable than any chronicles that come down to us in Latin or Greek characters. It reveals how every form of life descended from some earlier and simpler form.

The whole of the evidence in the rocks is vast beyond comprehension and makes bewildering demands on our mind. To any reader who knows no more of it than I can compress into this chapter it must seem somewhat unreal. As an indication of how actual and vivid it all is to men who spend their lives with it, I will give a description of a scene that has recently been uncovered in southern California. If you could drive west from Los Angeles over a boulevard, and step out of a car at Rancho La Brea, and walk through the dry fox-tail grass to look into a certain excavation in a bed of tar, you would feel the reality of geology.

All along the coast there are these outcroppings of asphalt, that has seeped through the shale and in some places formed deep pools of an extremely sticky

substance, which can be dug out only by using heated shovels. The edge may be covered by soil and become hardened, while the center remains tarry. Shortly before the World War an excavation was made in one of these pits, near Santa Monica, and there was discovered such a dramatic cluster of fossils as has never been seen elsewhere—saber-tooth tigers and elephants and mastodons that had been caught in this death-trap, mired in it, sunk, and been perfectly preserved. If I should find my horse dead in quicksand, I should not know more certainly how he died than I know when I look into this pit how these tigers died. The men who study oil shales know, as a matter of practical business, in what geological period the asphalt was made. It is a certainty that during the last minute of our reel elephants mired down in the California tar and trumpeted their distress, and that they were heard by a kind of tiger that no longer lives on earth, and that the tigers were attracted, and mired down to their death. The contorted bodies tell their story as plainly as a charred corpse in a house of Pompeii, covered with volcanic ash, tells how the man died. The episodes of all the history of evolution in the rocks have come from scenes which, though not so romantic, are as unmistakable as that in the asphalt pit.

CHAPTER XIII

THE EVIDENCE FROM GEOGRAPHICAL DISTRIBUTION

When a certain entomologist had studied a genus of beetles from Colorado south into Mexico, he prepared a chart showing where the different species live. "The study of the chart," he says, "gives clear ideas as to what the course of evolution has been." This little example will illustrate the experience of all modern naturalists when they map the locations of animals. If you could remove from their minds all knowledge of how species originate from previous species, their charts would have no meaning; all the groupings of animals would be a disorderly jumble. But the combined labors of collectors fit together into an orderly whole of animal life when evolution is understood.

To every modern naturalist the term "distribution" is a pictorial way of saying "evolution." If we could look at the world of life through his eyes, we should see that any great class of animals, such as the insects, is everywhere over the globe; to make a chart of them would be simply to draw a complete map of the land surfaces of the earth, except for those few areas where there is no life of any kind. Even one division of this class, say the order of beetles, would be spread almost as widely. But any one family of this order, the leaf-beetles, for example, would be absent from some desert areas where other families have found a way to live. Any one genus of this

family flourishes chiefly on one continent; it is to be found in only a part of the region that the family covers. Any one species of this genus—for instance, the potato-beetle before it found potatoes to eat—is restricted to a part of the territory occupied by the whole genus. When the range of any one species is thoroughly known, and its varieties charted, it appears that the species is most uniform and constant in the center of the range, and that the distinguishing characters fluctuate more and more in proportion as the specimens are gathered farther from that center.

The chart of the range of the species of any large genus of animals always shows a similar fact: there seems to be a center of the most typical forms, from which many species radiate; and each species radiates from its own center in varieties. If the naturalist assumes that each species is a group which developed from a preceding species, and that all the species of a genus branched out and pushed afield from some common ancestor, he can understand the distribution of animals. If he tries to imagine any other explanation of the locations of the different groups, he comes to grief.

All the facts of distribution point toward one fact —that the species of animals always develop by migrating *continuously* from their centers. Just as the evidence from the rocks shows that all organisms have developed continuously in time, from one age to another, so the evidence from distribution shows that they have spread by steady advance from a center where they originated. The chapters on classification and structure will show other phases of the evidence that life is always *continuous* in its lines of descent and location and classification and structure. The central truth of all the evidence in Part Two is that organic life, from whatever point of view we examine

it, appears as a *continuous* whole. We can not explain such a many-sided truth except by the theory that every form descends from a previous form.

If a zoologist finds some specimens of a certain species in Vermont and some specimens of the same species in Ohio, he can not conceive that they are unconnected. All the evidence of distribution declares that the species must live—or that eggs must have been transported, or that individuals must at some time have lived—continuously all the way from Vermont to Ohio. There is no evidence that the same species has ever originated in two places; it has only one origin, in one place, at one time; and from that origin it has spread out as far as it could go. And as a species spreads from its original center, it tends to alter, adapting itself to the new environments that it comes into. The whole theory of evolution would receive a severe shock if the facts of distribution did not always indicate that development has been continuous in time and place.

An illustration of the evidence that comes from distribution is seen in an exhibition of snail-shells in the American Museum of New York. They were collected in the island of Tahiti. The genus to which they belong has various species on many islands, but the five species in the exhibit are found only on Tahiti.* Each of these appears as a pushing, branching, varying group of forms. Number one has pushed into almost every valley, and nowhere varies much in its

*The *New York Times* of April 20, 1925, gave a striking account of what Professor H. E. Crampton, of Barnard College, had discovered about *Partula* on the island of Moorea, near Tahiti. "One of the three varieties found in 1909 had spread over the entire island. Its different valley colonies had become greatly diversified in size and color, presenting types unknown in 1909." Professor Crampton's earlier researches are in the splendidly illustrated *Carnegie Publication No. 228*, 1916; his later work is reported in *The American Naturalist* for January, 1925.

Photograph of an exhibit in the American Museum, showing the variations of a genus of snails in the Island of Tahiti. During the last twenty years new varieties have developed, and some species have spread over wider territory.
See page 206.

Another American Museum exhibit of the evidence that comes from geographical distribution—the finches in the Galapagos Islands, where Darwin made his early studies of evolution. See page 213.

white color; whereas number two is confined to one valley. Number three "has recently extended its range and differentiated into four varieties." Number four "has recently migrated and differentiated into varieties." Eight varieties of the wide-ranging number five have been found. If these descriptions of what the shells have been doing were the fancy of some one collector, we should pay no attention to them; they would mean nothing: But the same kind of description comes nowadays from all students of all kinds of animals everywhere.

Another graphic display of distribution is a large map of the western half of the United States, on which are the skins of eleven species of striped ground squirrels that range from Oregon to Wisconsin. The great family which embraces all the squirrels is world-wide, though it is strongest in North America. This genus on the map (*Eutamias*) ranges over only part of the United States. Each species is limited to a part of the whole area of the genus. When a scientist sees the large dark pelt of one species change through a series of species across the map to one that is light-colored and small, he reads a record of branching out from a parent stock and of altering to adapt to the new environments that were met as the genus spread. Every chart of every successful genus always reveals the same fact. When specimens are arranged according to where they live, they present a series of graded forms, as if their genus were a source of variant life that was forever trying to propel itself farther away, and that altered as it moved.

"Farther south," says one naturalist's report, "the species degenerates in size and is obscurer in color." That matter-of-fact statement would have been queer jargon to Darwin in his boyhood, for it represents a group of forms as a fluid, fluctuating

mass that changes while it grows toward a new habitat. But to the Darwin of middle life it would have sounded like a perfectly natural description, because a species at one end of a wide range is bound to be different from what it is at the other end. "In different localities," says the naturalist, speaking of another species, "it tends to the development of distinct local forms." Every study of distribution, of any plant or animal, shows the same tendency.

We have been attending to some petty examples. Take a very large one, as stated by Professor H. F. Osborn in 1900: "The fact that the same kinds of mammals and reptiles appear simultaneously [*i. e.*, during the same geological periods] in Europe and in the Rocky Mountain region is strong evidence that the dispersal-point is half-way between." He predicted that such an origin would be found in Asia, and he named the fossils that must some day be searched for there. In the spring of 1922* the American Museum expedition to Mongolia began to find them, and in generous measure. When any theory of distribution has produced such successful prophecy as that, it is well tested.

The greatest test of the theory is on the islands. Some of these are very close to a mainland, and some are very remote; some have been separated very recently, and some for several geological periods, and some never were connected with other land; some could be reached by immigrant animals of certain sorts, but not by other sorts; they might preserve old species with little change, or they might force old species to develop new adaptations. Thus they are like experiment-stations established in the ocean to give proofs of whether or not all species develop by continuous descent and in continuous lines of migra-

*Still more striking discoveries have been reported in 1924 and 1925.

tion. If evolution were not true, its falsity would be sure to appear in some of the facts of animal life on islands. If it is true, then the following conditions would have to be found:

1. There would never be upon an island an animal whose ancestors had not reached the island.

2. In proportion as islands are farther from a mainland, or have been longer separated from it, the animals on them should be more different from those of the mainland.

3. But in some cases (for example, if some fierce competition of the mainland were removed on the island) we should expect to find that species had altered less on islands than on the mainland.

4. The kinds of animals would, in a general way, be numerous in proportion to the ease with which they could reach the island—for example, by flying, swimming, being borne in currents, being drifted by gales.

The facts of the distribution of animals on islands are in accordance with those conditions, as the following descriptions will show.

Long Island is detached from the mainland by only half a mile of water, and the separation was made in very recent times. Hence we should expect that the animals and plants on it would be only very slightly different from those on the mainland. That is the fact. When it became an island, it was stocked with the same species that were on the New York shore; and it has been so close to that shore that there could be much migration. There has been little time for new varieties to develop, and there has been only partial isolation from the life that swarms on the mainland.

If you go eight hundred miles southeast in the Atlantic, you come to the Bermuda Islands, twenty square miles of low-lying limestone hills surrounded

by coral reefs, a small remote bit of land that has long been separated by hundreds of miles of water from the nearest Bahamas. Here we should expect to find the animals very different from those of our nearest Atlantic coast and somewhat different from those of the Bahamas. Such is the case. There is only one backboned animal which is native, a lizard that is found nowhere else in the world. Yet among the birds there are no peculiarities—no species that is not found on the mainland. Among the shell animals and insects, however, there are extraordinary differences—a great array of peculiar species. A zoologist who reasons about this problem of distribution asks, "Why should birds be just the same as on the mainland, while the reptile is a solitary curiosity and the shell animals are widely different?" If he could find any sensible explanation that did not depend on the evolution of species, he would become famous; and there are hundreds of eager scientists who would be glad to work unremittingly many years for such a reward. But no zoologist ever wastes a precious hour on such a mad venture. He would have a better chance of finding out how to control thunderstorms than of finding a non-evolutionary clue to the assemblage of animals in Bermuda.

If every species has developed from a previous species by gradual alteration, and if every species is a varying group of life that is always prone to adapt itself in old surroundings or in new ones, then there is no mystery about the life of Bermuda. When the large continental island east of our coast, "Antillea," was broken up into fragments during the last great geologic era, the northernmost bit that became Bermuda was stocked with the same genera that had populated the whole of Antillea, but that had varied a good deal since Antillea was, long previously, sepa-

rated from the main continent. Then the species, in their isolation, entered upon a period of separate development. Some kinds of animals had been sparsely represented in this northern tip: lizards had been so scanty that only one species has survived to our time, and it has altered to a unique form. Of the abundant shell-fish many have remained practically what they were; many have branched into varieties; many have changed so far as to become new species. The same history holds for insects. For many animals Bermuda has been an isolated home: they could not leave it, and others of their kind could not reach it. But many shell-fish and insects and seeds have from time to time been brought from the southwest by gales and the ocean currents, and have thus replenished the local types. No snake or warm-blooded animal ever has survived such a long ocean journey to propagate its kind. As for birds, they have no more been cut off from Bermuda than they have been from Cuba or Georgia; in their migrations they visit it regularly; and hence there has been no more reason for the development of a new species on the islands than there has been on the mainland. When geology and evolution are applied to these islands, they furnish an understanding of the history of life there. Without evolution no rational history can be conceived.

The Azores are more isolated than the Bermudas. From water that is two and a half miles deep, in mid-Atlantic, they rise, not a thousand square miles of area, in complete isolation—eight hundred miles from the nearest point of Europe, nine hundred from Africa, and one thousand from North America. The life on these islands would be an impossible enigma without evolution. When that theory is applied, all can be understood. One kind of bird has long made the

Azores its home, and it has become a unique species; but otherwise the birds are not peculiar. Most of the insects and shell-fish are like those of Europe; some have been much modified; all could have been immigrants borne by the accidents of storms and currents. No backboned animal without wings is to be found there except those that have been brought by man. The islands have been almost entirely stocked with European forms of life, some of which have altered into new varieties and species.

It will be safe to say at this point that for sixty years there have been sagacious zoologists who wished to find some problem of island distribution that evolution could not solve. We laymen are almost sure to suppose, even after many repetitions, that "the scientists" have determined to support their pet theory and to adjust all the facts of island life to fit it. Doubtless some of them have had that attitude. But all the while there have been many more ready to challenge and oppose the theory. During the sixties most of the older naturalists were in that camp, and they bent their energies to show that evolution was not necessary to unriddle the Bermudas and the Azores; they figured out "land bridges" and "dying out of species" and other possibilities to account for the facts. No modern geologist can find any support for their theories. No modern scientist knows of any way to understand the species of the Azores except as a gradual change of species into other species.

If a summary is made of all the facts known about the distribution of life on volcanic islands, there is always confirmation of evolution; and there is never any crucial evidence against it. Men have seen islands so recent that not a vestige of any life was on them. On other very recent islands there have been seen specimens that have been carried from the nearest

land and that are identical with the species on that land. No life has ever been known to originate on a new island; it is always brought there as a continuation of previous species. Most of the immigrants to new land come from the nearest islands, or they are preponderantly from the mainland. There is never any species that might not somehow have arrived at that shore from another shore. When animals have been for some time in this new home—even for so short a period as a hundred years—their variations begin to take effect. Quite marked varieties have been seen in rats and pigs and rabbits, even during the three centuries that men have been able to observe such changes. Every peculiarity in the distribution of life on islands is consistent and comprehensible on the theory that no species ever originates without ancestry and that most species tend to alter gradually and to send off new varieties, which will become new species if time is long enough. The composite picture of the distribution of plants and animals on islands is like a photograph of evolution. No details gathered from Hawaii and the atolls of the South Pacific and Iceland are discordant with the picture; all fit into place as part of a rational scheme of things.

A classic example of island life is that in the Galapagos, more than five hundred miles west of Ecuador. When Darwin landed on them, long before he believed in any theory of evolution, he was struck by the similarity of the life to that of the mainland. "Almost every product of the land and water," he reported, "bears the unmistakable stamp of the American continent." The conditions of life there were not very similar to conditions on the mainland; they had more resemblance to the climate and soil of the Cape Verde Islands, which are off the west coast of Africa. Yet the life of the Cape Verde Islands is

African in character, and the life of the Galapagos is South American in character. A good observer can not resist the conclusion that each group of islands has been stocked from the neighboring continent. If he tabulates the evidence from all islands, he finds his conclusion strengthened by everything that can be learned. Nothing has ever appeared that contradicts the conclusion. And another conclusion is quite as inevitable: most of these animals on the Galapagos are not now the same as when their ancestors migrated, but have altered so far as to have become new species. The evidence of distribution on islands always points one way.

The most remarkable confirmation is the great island of Madagascar. It is separated from Africa by only two hundred fifty miles of water, and yet its life has much less resemblance to the African forms than the life of the Azores has to European forms—though the Azores are four times as far away from Europe. Why should evolution have anticipated that this would be the case? Because Madagascar has been separated from Africa vastly longer, and there has been time, in its large territory and differences of environment, to develop greater differences of form.

Madagascar has also preserved many types that are nearer to their ancient ancestors than any species that survived in Africa. It is like a museum where the naturalist may see forms that he could only have conjectured from the animals that now live in Africa.

The greatest collections of these zoological antiques are in New Zealand and Australia, where the animals that bear their young in pouches (the marsupials) are the dominant type. There was a time in geological history when the marsupials were common over the world; but they have become extinct

(except for the opossums) everywhere but in New Zealand and Australia. There, cut off from the rest of the world, they have developed into flesh-eating animals that look like wolves, into gnawing animals of a rat-like appearance—in fact, into forms that outwardly resemble almost all the orders of placental mammals. The animal distribution in Australia is to the evolutionist what a discovery of an Egyptian tomb is to the historian; it sets before his eyes the facts of bygone ages.

When geologists map the fossils, showing in summary form where the different kinds lived at different periods, the distribution in past eras tells him the same story that is everywhere attested on the islands at present. If a naturalist charts the habitats of birds or of wasps or of mastodons, he finds that he has made a sketch of evolution. If a botanist maps the pines or orchids or palms, the sketches of their distribution are sketches of evolution. Knowledge of distribution always strengthens the assurance that animals and plants have been developed by a process of evolution.

CHAPTER XIV

THE EVIDENCE FROM CLASSIFICATION

Last year a celebrated lecturer dared to make this statement to an audience: "There are myriads of living creatures about us, and yet not one is in transition from one species to another; every one is perfect." He will never know how untrue his declaration was. And even if he were curious about the facts of the case, it would be hard to show him his error, because the reality is so different from anything that he cares to talk about. In fact, he has stated a half truth that can not be flatly denied, and it is the particular half truth that has caused the most skepticism about evolution. It is worthy of a full explanation.

If a college boy were debating with him, the most telling retort would be to ask, "Did any one ever see a stratum of rock rise from the ocean?" The answer is no. And yet any intelligent person must admit that strata have risen from the ocean; in some places we can see, with a strictly correct imagination, that rocks are now rising. It is so with species.

But comparisons do not prove anything. Put the question to a botanist: "How can you believe that one species changes into another if you have never seen such a change?"

He will answer: "Because we very seldom see a species stand still. Almost every species is varying right before our eyes. There is hardly such a thing

as a fixed species that you can describe and count on and distinguish from all other species. They change and blend and weave in and out among each other so much that a botanist may find it hard to tell what any one species is. I might quote what an instructor of mine used to say about another topic: 'You won't understand it till you've lived with it.' Select some small genus and live with it a while."

If you, unlike most people, care to spend a few hours with the genus of spruces, you can get at least an inkling of what the professor meant. You pull down your trusty *Britannica* and find eleven lines; only two species are named, and you are referred to the article on Fir. It appears that there are many genera commonly called "firs," and that two of them have always been much confused. But you at least learn that the genus you are trying to find is *Picea,* and you see the names of three species. The encyclopedia will do nothing more for you. So you try the *Century Dictionary.* You learn that *Picea* and *Abies* have always been much confused, because the leading botanists have had different opinions about the best way to classify; but that the trees you know as spruces are now generally called *Picea,* and that the true firs are called *Abies.* That is queer. Last summer in the Adirondacks you saw no possibility of confusing the two. You learned readily to tell a spruce from a balsam fir and to recognize the hemlock and the pines. The four kinds of evergreens were "perfect species" and could not be mistaken for one another. To refresh your memory you look up hemlock. Strangely enough it is to be found only under "hemlock-spruce" and is defined as "an American fir." Yet it is not of the genus *Abies,* but is of the genus *Tsuga.* If you now look up this genus, you will be on the trail of *Pseudotsuga* and will discover that "by Eichler,

Bugler, and others it is united with *Tsuga,* and is variously called Oregon pine, Douglas fir, or Douglas spruce." Since life is short, you step back from this snare and stick to the narrow road of *Picea.* It appears that "Asa Gray and others included the genus under *Abies,* but that present usage calls the spruces *Picea,* which includes about twelve species." Now why, in the name of all that's orderly, should the dictionary say "about"? Why shouldn't it count up exactly and say that there are eleven or fourteen?

Don't allow yourself to grow excited and to set your heart on finding out just how many species of *Picea* there are. For you never can know; nobody ever will know. The different forms of *Picea* could be lumped into seven species, or could be split into forty. A species is merely what a number of men think. Naturalists try, for their own convenience, to agree so far as they possibly can; but agreement by all classifiers is exceptional. Ask any botanist to name for you a species that is "perfect and distinct" from all other species. You might as well ask him where the Pacific Ocean ends and the Indian Ocean begins.

Thus you have one preliminary peek at what classification means. Look a bit farther. Read the descriptions of seven species of spruce: black, white, Norway, Himalayan, tideland of the Pacific coast, *engelmanni* of the Rocky Mountains, and *parryana,* "a rare and local mountain species of the western United States." If you look under "king-pine," you will find a ninth species, *webbiana.*

If you care to spend ten hours for a little more understanding of what classification means, you will discover that even a large inclusive genus of evergreens is not definitely marked off from other genera. It is hard to follow the ins and outs of the characters

of cones and leaves and bark, so as to find some one way in which all of a certain large group can be positively distinguished. What holds good as a distinction between spruces and firs in New Hampshire and Idaho takes a backward twist in India. In the volumes of a big manual you can see how one botanist after another has spent perplexing years in assorting by some different sets of characters what previous workers had arranged in another series. A genus is not a firm unmistakable type; it is like a fluid mass of life that flows among and interlaces with other related types.

And a species! It is a set of opinions formed by men who have tried to group the principal variations of a genus of forms that shade into each other. Every botanist who deals with the genus wishes that the divisions of it could be readily told apart, but he seldom encounters a distinct species. When he completes his chart of a genus, he has made—against his will and with great labor—a display of variations that may be distinct at their opposite ends, but that blend where they meet.

Every person who is not a botanist takes it for granted that a spruce is a spruce. If he learns to tell a spruce from a hemlock and a balsam, he is proud of his knowledge. Then some day he may have to cut and trim a number of young spruces and peel them for tent-poles. They all look alike; unmistakably they are spruces, cut down within an area of six square rods. But he learns that the bark of one comes off easily in long strips, and that the bark of another clings so that it can only be hacked off in bits. As he observes these trees in his neighborhood, he realizes that they vary in the shapes of their tops, in the posture of the limbs, in color. A dog would find that spruces differ in odor; a chemist would find that they have varying percentages of resin and sugar.

Within the species, as it grows in one district, there are varieties, which vary among themselves, until in the last analysis every tree is a unique individual.

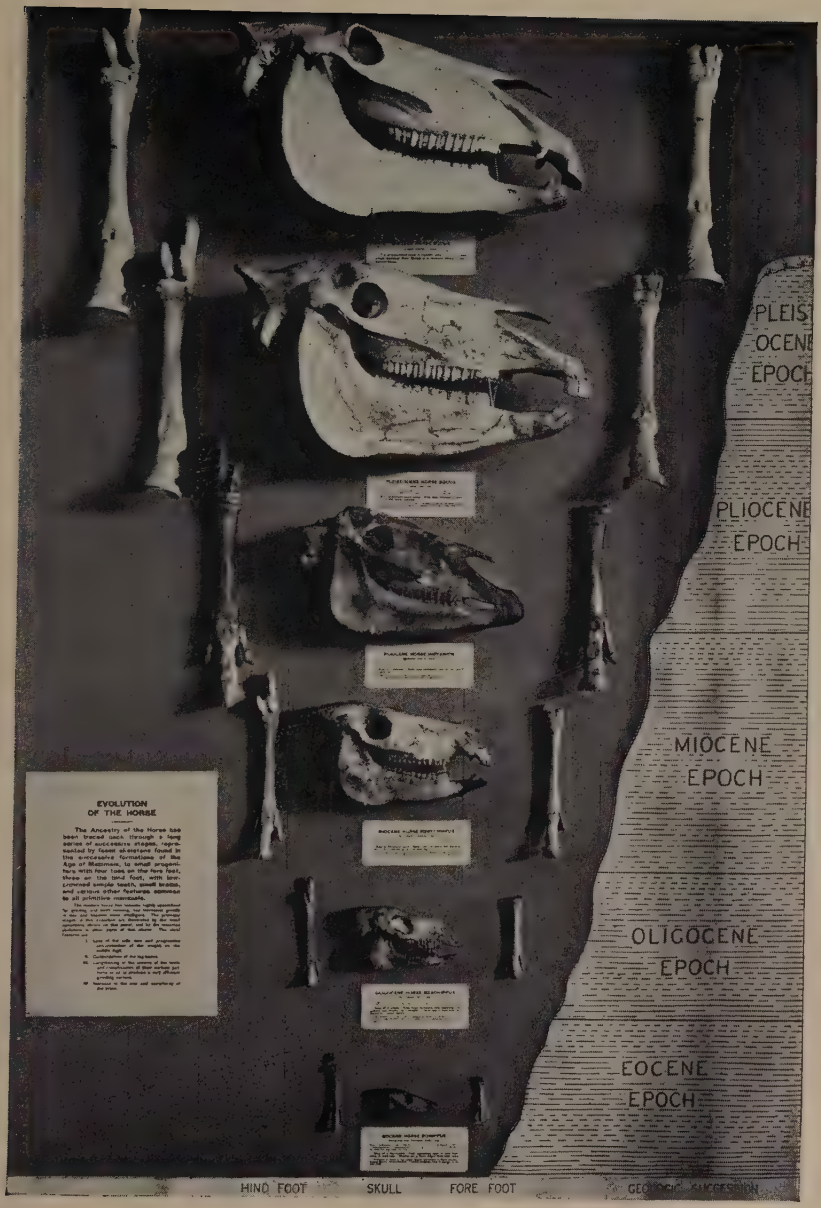
Suppose that some wealthy young man became engrossed in the genus *Picea* and determined to make a fad of it for some years; suppose that he followed it from Newfoundland to Oregon and around the world, taking his time to wander for many days in each locality, to make complete notes of variations in characters, to study constantly for some better scheme of classification of "about twelve species." After three years of travel and examination he spends a year in studying all the available literature of the subject and noting the discrepancies and ignorance of all authors—not one of whom could spend so much time in this limited field. Now he is an expert. But realizing that his knowledge is narrow, he studies general botany for three years more, specializing on the conifers and writing a doctor's thesis on a genus which is intermediate between *Picea* and *Abies*: "The Paired Species of *Tsuga*, a Study in Ontogeny to Determine Whether *Pattoniana* is a Species or a Genus." You see, classification is such a difficult art, requiring such a long and severe apprenticeship, that no man is fit to determine species of spruce until he has proved by work in allied genera that he is a competent observer and that he has good sense in reasoning from his observations. If our friend can show some acuteness in his criticism of Professor Lemmon for erecting *Pattoniana* into a genus *Hesperopeuce*, he will be listened to respectfully when he proposes a classification for *Picea*.

Just as he begins to prepare his monograph, his eye falls on a startling piece of news in a scientific journal: a new field of research has opened for all students of conifers—the fossil *Bennettitales*. It

flashes upon him that during ten years he has only looked at the surface, that there are facts of woody structure and mode of cone-bearing that may shortly upset whatever he publishes. He reads: "We find ourselves profoundly ignorant of the values of the characters of living plants for differentiating species. . . . There is difficulty in mastering the overwhelming mass of living species with which the fossils must now be compared." Still there is hope, for "In small genera of gymnosperms [of which the conifers are a part] the comparison may not be crushingly burdensome; Berry, Halle, Thomas, Bancroft, Antev, and others have already done pioneer work. . . . The detailed chemistry of different cell units is now gradually being correlated." For a few days his spirits are low, and he meditates a return to collecting postage-stamps. But courage returns. Here is a fascinating vista of difficulties to overcome. Perhaps if he studies geology and paleobotany and chemistry and recent cytology for five years, he may qualify to understand what Berry and Halle and the rest are about; he might even join in their exploration of the cells of conifers that lived ten million years ago. If he signs for such a cruise into the distant realms of species, he will sail far beyond the bounds of this little elementary book on the outlines of the Evolution Theory. Of course he will never return to classifying spruces; it is a job so far beyond present knowledge that it must be carried out by the next generation. He will go on and on toward an understanding of how no species is ever distinct, but is a branching group of forms, which branched off from an earlier stem, which grew from a still earlier stem. He will never see in future—no scientist ever sees—a species that is "perfect" and that stands still to let itself be classified as a fixed form of life.

You have seen one bit of an indication of what is in a botanist's mind when a breezy layman asks, "Have you ever seen a spruce change to a birch?" He can only smile—if he is good-natured enough—and say no. In that sense no student of plants has ever seen a species, in nature, change to another species. But such a question is the merest crude ignorance. In every other sense the botanist sees species changing. Species have hundreds of times been brought from nature to cultivation and have branched off into widely different varieties in a few years. When the ancestry of a species is traced back in geology, it is seen as a stream that alters from one period to another. A species is no more an everlasting creation than a mountain, and no more independent. Mountains and species are made out of previous mountains and species. A carpenter could as easily believe that houses are miraculously made out of wood that never grew in trees as a botanist could believe that any species was ever made without descending from a previous species.

The little experience with spruces could be duplicated with almost every genus of plants or animals. In some cases, of course, there is a whole genus—yes, a whole family—that is quite distinct from any other form that exists—such as the tuatera lizards of New Zealand or the horned hog of India. In the Field Museum of Chicago you may see a coon-like dog which is the only species of a genus, and an African rabbit that looks like a kangaroo, which is the only genus of its family. Such solitary types are just what we should expect to find sometimes if species change into other species; for there have always been groups that fell behind in the struggle for existence, that did not branch out into new forms, but gradually became extinct. The fossil record is full of such examples.



This series, showing the evolution of the horse, is the most famous piece of evidence discovered by paleontologists. See page 244.

This mammoth was found in Indiana. Mammoths have been dug up in great numbers throughout the northern states. So recently have they become extinct that early men in Europe drew pictures of them.

There are in the world to-day many unique plants and animals that form the dying tip of a twig of the tree of evolution.* But otherwise, in the case of any type that is at all prosperous, there will be varying forms, impossible to reduce to order by any hard-and-fast lines of classification. Each type is like an area of life: in its center it is decidedly different from the central forms of other types; at its edges it melts into surrounding edges.

When the classifiers of insects first saw the *Hypocephalus* of Brazil, their brains would have reeled if they had known nothing of evolution. Here was a monster three inches long that was composed of family elements apparently as dissimilar as the characters of the cow, the dog and the squirrel. What could be done with him? If classification had to deal with fixed species, there would be nothing to do except surrender. But if life is understood as a variant stream of forms, this strange creature has a place in a rational universe, and comes to our museum as a witness to the course of evolution of beetles.

We have been long enough cramped in the limits of single genera. Take a flight into a wide region of classification and see what it looks like. One phylum would serve as well as another. Try sponges. We could guess that there must be several kinds of them, because some are so soft and some are dark and coarse. Take three years off for the study of them.

They live on every seacoast. If you should decide to amuse yourself by classifying them without reading what zoologists have learned during the past century, you would hardly make a beginning on the Gulf of Mexico in three years. By that time you might find out that you could not tell the difference between one sponge and a hundred sponges. It is not possible to

*See the diagram on page 187.

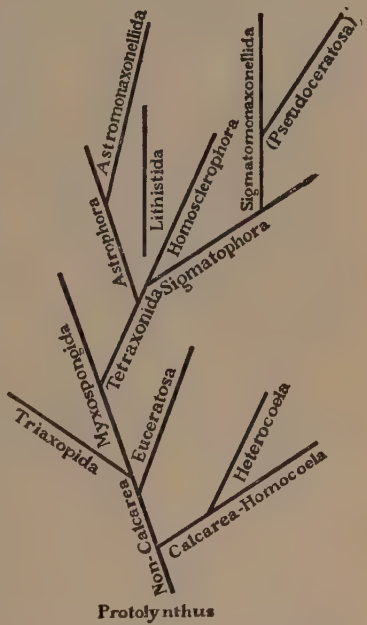
decide surely on any dividing line between an individual, all of whose cells work together as your own cells do to make one individual, and a colony of sponges which remain separate individuals. Some species are clearly of one type and some are clearly of the other; but the two types blend.

Do you begin to weary of the "blending" of types? That is what every classifier wearies of. He can not count on finding any border to any type that seems distinctive. This great tribe, A, is absolutely distinct from another tribe, B; and you suppose for quite a while that they have nothing in common. But as you gain knowledge, you discover that A is not fixed; you gather specimens that form a continuous series, shading off from it toward the B type. The same is true of B: it shades toward A. They blend. In proportion as a group seems constant, it is small and unsuccessful; in proportion as you will find it wide-spread and victorious, its forms are variant.

If you are sagacious and persistent, you may learn after twenty years that there is a fairly well marked division of all sponges into those that have limy skeletons and those that have flinty skeletons. The first group is small. You distinguish two kinds of them: (*a*) those that are lined with protruding cells; (*b*) those that are lined, partly at least, with a smooth floor of cells. Even in this *b* group—much the smaller one—there is crisscrossing with a third group, somewhat unlike either *a* or *b*, so that you are in despair about them. As for the flinty sponges, it will take you months to arrange the descriptions of them from your hundreds of note-books; and when you have made a preliminary assortment on the basis of the cells with which they are lined, it won't do at all. You see another possibility: perhaps you can classify them by the hardness and softness of their skeletons.

If you persevere, reading the great treatises that scholars have made, and repeat your observations for several years, then you will understand that a fixed species hardly exists in nature, that a species is a compromise of opinions.

For a century men have been at work on sponges. So far the classifiers can not agree on any mode of arranging the phylum. It would appear a wanton and meaningless mass of unreason if we did not understand that every form has branched from a previous different form and tends to continue to branch into new forms. With this knowledge for a clue, species are being assorted, and some time they will be straightened out. As more is learned in other departments of zoology about the principles by which forms evolve, the knowledge can be applied to throw light on sponges. No zoologist nowadays can conceive of classifying by any other clue. By it he is led to understanding; without it he gropes and stumbles in the dark.



Chart, after Dendy, of the classes and orders of the sponges, which have furnished specially interesting evidence of lines of descent from extinct forms. Compare this with the chart of a sub-genus on page 228.

A glance at the diagram of one classification of the sponges will illustrate how all classifiers conceive their business in the twentieth century. All life is thought of as as a process of form branching from form.

The most significant item in the chart is the line marked Lithistida, which is left unconnected. When the chart was prepared fifteen years ago, there was no way to determine whether this group was a "grade" or an "order," or whence it sprang. Instead of guessing about its origin the classifier indicated his ignorance.

Another view of the sponges will show another truth that classification regularly reveals—the relative largeness and smallness of the divisions. It is not entertaining; skip it if you don't like the looks of it. For those who linger with it a minute I will explain that the steps downward in subdivisions are shown, from greatest to smallest, by "One, I, 1, a"—representing respectively sub-phylum, class, grade and order. The table shows only the large preliminary groupings, larger and more general than families, and far above genera. The size of type indicates, very imperfectly, somewhat of the relative number of families in each division.

Sub-phylum One
- a. order
- b. order

Sub-phylum Two
- I. Class
- II. Class
  - a. order
  - b. order
- III. Class
  - 1. Grade
    - a. order
    - b. order
    - c. order
  - 2. Grade (or this division may belong under Grade 1 as the d order)
  - 3. Grade
    - a. order
    - b. order
- IV. Class

We have seen the tree-like appearance of the largest divisions of a great phylum. If we should take the next step down in classification, and should chart, for example, the *b* order of one of the grades, we should produce just the same kind of diagram of branchings; the big bare limbs of orders would each have clumps of branches—the families. And each of these families would send out clumps of smaller branches—the genera. Each genus, if it was prosperous, would fork into many twigs—the species. And each flourishing species would have several leaves—the varieties. And the leaves might be sending forth buds—some sub-varieties.

The diagram on page 228 pictures one man's classifying of a sub-genus of the big, black *Eleodes* beetles of the Southwest. This man would have been lost in the mazes if he had not known how to look for the course of development of each species and variety that he found.

Suppose that you had encountered Mr. Blaisdell as he returned from his six-month collecting trip over the sage-brush plains and up the bouldery barrancas of the Mojave Desert, and suppose that you had asked him what a species is. Perhaps he would have sent you a copy of his bulletin, with this passage of the definitions marked: "Heterotype=an individual that forms an extreme of a specific or varietal series. Mesotypes=individuals connecting the extremes of a series. Amphitypes=individuals that simulate another species. Monotype"—and so on through polytype, sexitype, and others. So absolutely non-perfect were the species and varieties that they can not be conceived or in any way classified except by paying attention to that greatest truth of nature, that a species is a fluid form of life.

Pause a minute to take stock of the labor that Mr.

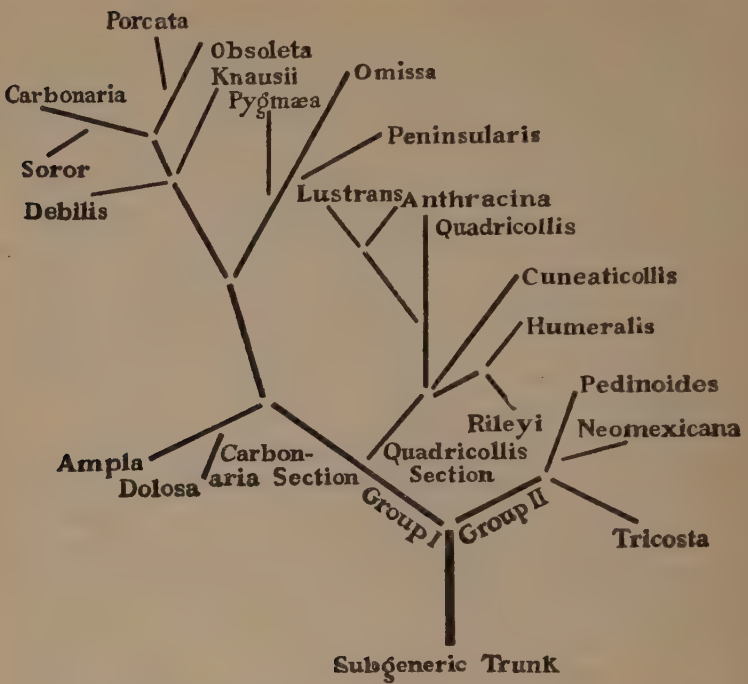


Chart of one section of a genus of large, black beetles, after Blaisdell in the *United States Natural Museum Bulletin 63*. It shows the same sort of branching that is seen in the chart of the whole vast phylum of sponges on page 225.

Blaisdell put into determining the twelve species and eight varieties of this one part of a genus of beetles. And his labor was only a portion of the whole; for six specialists had worked in the genus before him. Multiply the total labor of these seven men by eight thousand, in order to know how much effort it took to classify all the beetles. Multiply the product by some large factor, in order to have the sum of expert toil that has been spent upon classifying all animals. Double the product, so as to include all the classifying of plants. Then—and not till then—you will appreci-

ate slightly the amount of evidence that is furnished by classification.

A classifier never can find a sharp line of demarcation between different groups. Between most species there are varieties that bridge the gap; between genera there are interlocking species; between families there are dove-tailing genera; to separate orders so clearly that no family will bridge the gap is usually impossible. Classification always indicates that if our knowledge could ever be complete we should see that there never had been any gap anywhere, but that all transitions have been continuous, over bridges of variation that dropped out and disappeared from the record. "At this point," we are told by botany, "the distinction between flowering and flowerless plants breaks down." So deep a rift as that is well bridged over. The more men learn of fossil plants and animals, the more they are taught that in past times there have been bridges between forms that to-day seem wide asunder. Life has been a whole, and there has never been any such thing as a separate species that was not attached through its branching ancestry to every other form that ever lived and branched upward from the beginning of life. A modern classifier can no more conceive of a species without ancestry than a biologist can conceive of an animal that had no parent.

I will close the chapter by a comment on the men who classify. So far as a rough count of the different sorts of sponges can be made, there are about two thousand five hundred species—only two thousand five hundred. It is well for us amateurs to try to stretch our imaginations to the classifying of the sixteen thousand species of spiders. Perhaps we had better excuse ourselves from trying to imagine the extent of the intricate labors of classifying the

sixty-one thousand species of mollusks. Even if we were willing to strain our minds to the breaking-point, we could not conceive the total of patient work that has gone to the making of a chart of all the animals or all the plants. Of this vast domain of classification no modern scholar can know thoroughly more than one corner. The botanists and zoologists are a great corps of tireless and clever campaigners against the mysteries of nature. No one can command them; there is no discipline. Some delve in coal mines for ancient ferns, some spend the years viewing grasshopper eggs under a microscope, and others dredge the depths of ocean or thread the tropical forests or study agricultural pests at home. No horde of self-willed barbarians were ever so free to spread where they like and think what they choose. Yet they all think one way and—whether they will or not—contribute to one fund of ever-increasing knowledge of one subject. Whenever they classify truly, they extend the kingdom of evolution.

CHAPTER XV

THE EVIDENCE FROM ARTIFICIAL SELECTION

The kind of evidence that comes from artificial selection has been outlined in Chapter IX—that is, the ways in which breeders select the variations provided by nature through a series of generations, piling them up as they occur in a desired direction, until they gradually develop a race that is widely different from the one with which they started. In this way many plants and animals have been slowly changed into forms so unlike their ancestors that they appear as different as a new species or even a new genus. Examples were given of two ways in which new varieties arise: (a) by selecting a series of slight variations,* as in producing new kinds of pigeons or changing a small single daisy into a large double chrysanthemum; (b) by the sudden appearance of a new breed, as in the case of the hornless cattle or a new kind of peach. This sort of evidence has always been persuasive; it can be seen in operation; it indicates that all kinds of life, wild as well as cultivated, are variable and are prone to change to very different forms.

There is no need here to add pages of further illustration, but there is need of showing in Part Two that the facts of artificial selection are an important kind of evidence for evolution. I will give a few examples

*For variations that can not be cumulated see Chapter XXIV, Section III.

which supplement Chapter IX, and will then explain why this line of evidence is, if taken by itself, incomplete.

Darwin founded much of his reasoning on his knowledge of the breeding of animals and plants. Indeed the evidence was so important to his theory that in 1868 he published two large volumes, *The Variation of Animals and Plants under Domestication,* as a sort of "case-book" for the *Origin of Species*, a storehouse of evidence that was too bulky to go into the *Origin.* So exhaustive was this great collection of facts that it is still cited as the principal source of information about artificial selection. I give below five quotations from the book, which show how differences brought about by artificial selection may be very great, very firmly established, and sometimes fitted to succeed in wild life.

1. The Japan pig is so distinct in appearance from all common pigs that it stretches one's belief to the utmost to admit that it is simply a domestic variety. . . . The modification of the skull in the most highly cultivated races is wonderful. The whole of the exterior in all its parts has been altered: the hinder surface, instead of sloping backwards, is directed forwards, entailing many changes in other parts; the front of the head is deeply concave; the orbits have a different shape; the canines of the upper jaw stand in front of those of the lower jaw, and this is a remarkable anomaly; the knobs at the base of the skull are so greatly changed in shape that no naturalist, seeing this important part of the skull by itself, would suppose that it belonged to the genus of pigs.

2. The Niata cattle of South America have a forehead that is very short and broad, with the nasal end of the skull curved upwards. The lower jaw projects beyond the upper. Even the connection of some of the bones is changed. Scarcely a single bone presents

the same shape as that of the common ox, and the whole skull has a wonderfully different appearance.

3. In the genus *Auchenia* there are four forms—the Guanaco and Vicuña, found wild and undoubtedly distinct species; the Llama and Alpaca, known only in a domesticated condition. These four animals appear so different that most naturalists, especially those who have studied these animals in their native country, maintain that they are distinct species. . . . Now that we know that the domesticated species were systematically bred and selected many centuries ago, there is nothing surprising in the great amount of change which they have undergone.

4. The humped cattle of India have run wild in certain parts of Oude and Rohilcund, and can maintain themselves in a region infested by tigers. They have given rise to many races differing greatly in size, in the presence of one or two humps, in length of horns, and other respects. . . . There are magnificent wild bulls on the bleak Falkland Islands in the southern hemisphere.

5. We must not overrate the amount of difference between natural species and domestic races; the most experienced naturalists have often disputed whether the races are descended from one or from several aboriginal stocks, and this clearly shows that there is no palpable difference between species and races.

The statement that "there is no palpable difference" between the results of artificial selection and of natural selection may be misleading. For it is a fact that no artificial species has been produced which can not breed with other species descended from the same stock; and that means that in the brief time of man's selection no such deep and wide separation of types has been made as nature has created. Artificial selection is by no means a proof of natural selection; it is only an index to a strong probability.

Yet some of our domestic races are so ancient, as human history goes, and so thoroughly distinguished from any other forms existent in the world, that they seem to justify Darwin's emphasis. No one has ever seen a wild llama; we know that it has been domesticated in Peru for four centuries and that it was probably derived from the wild guanaco, but it exists now as a separate species. The Arabian camel has never been seen except as an animal domesticated by man. Our Indian corn has never been seen wild, and no ancestry is known for it. The same is true of wheat. The differences between these results of artificial selection are certainly not "palpably different" from the species in nature.

Certainly none of the hundreds of practical men who work in our agricultural colleges know how to tell the difference between artificial and natural species, nor are they much interested in the difference. They all work on the supposition that the variations and sports in nurseries are of the same kind as those that occur in nature, and that the new varieties they produce are not palpably different from what nature has produced through all the ages. If sports from buds of sugarcane and potatoes are so important in artificial changing of species, presumably the same sort of sporting has been a factor in nature's evolution. If the Seneca cherry of 1923 sprang into existence with new qualities—ripening early and having a spicy flavor—presumably such sporting seeds have had their share in causing nature's results. When Pennsylvania State College gradually develops a tobacco leaf that has only half the ordinary percentage of nicotine, the experimenters suppose that they are dealing with the same sort of mechanism which has caused tobacco and potatoes to branch from the common ancestry that every botanist knows about in nature. Of course the

experimenters may be wrong; but thus far no one has made any progress in discovering a difference between their results and nature's results. All men who collect and direct the variations of plants and animals suppose that their work is evidence for the Evolution Theory.

The strongest part of the evidence will bear restatement in this chapter. If all artificial selection dealt only with domestic plants and animals, the evidence would be weak. The fact is that all artificial selection begins with a wild species. In recent years many experiments have been made with plants that were never domesticated, and it appears certain that, if an experimenter is patient enough and has enough time, he can always discover variations to work with. It is believed that every wild plant, and presumably every wild animal, could be developed gradually by artificial selection, into a form that is very unlike its present form. It would seem that artificial selection, however violent and abnormal it may be, is simply a use of the machinery of natural selection. Artificial selection may pull the wrong levers and may spoil the engine, but it indicates that the engine of natural selection is there.

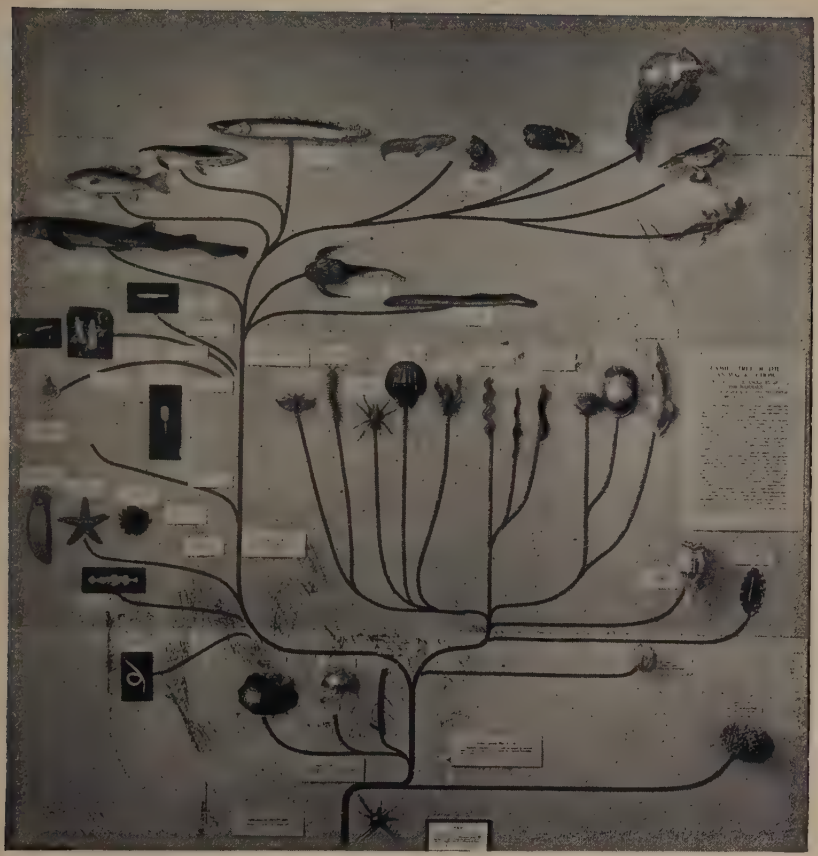
CHAPTER XVI

THE EVIDENCE FROM THE STRUCTURES OF ANIMALS

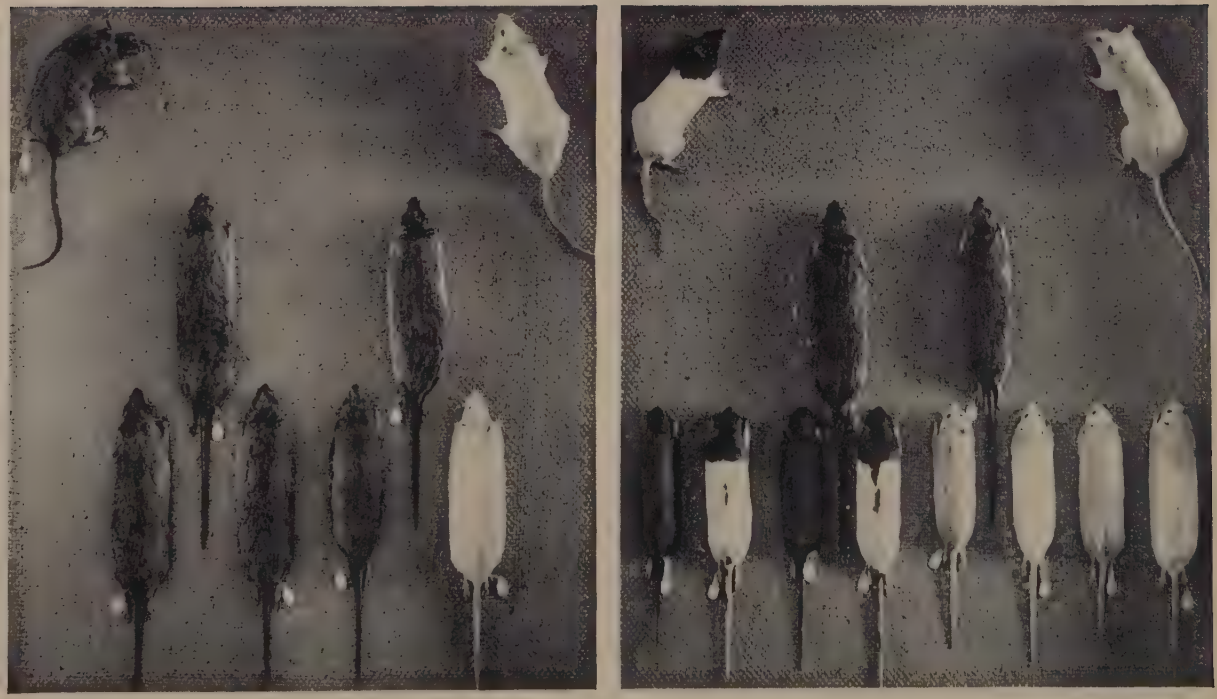
In the American Museum of Natural History there is a chart of the supposed course of development of animal life, from one-celled creatures to mammals. The makers of the chart would wish us to emphasize "supposed" while we study the branching lines of their exhibit; for they know better than we how mazy and back-tracking the paths of evolution have sometimes been and how puzzling is some of the scanty evidence.

On the other hand, they would wish us to know that in many ways the evidence is copious and that it is extremely probable that their exhibit represents the main lines of evolution correctly. The principal parts of it were known fifty years ago, have been subjected to the severest criticism, and have stood the test. It is likely that the improved chart which can be made fifty years hence will differ only in some details. And the men who planned this diagram of life would wish us to understand something of the vast labor that has been necessary, by thousands of scientists in many departments, to secure the knowledge which made their chart possible. There is no guesswork in it. It represents keen observation and close reasoning.

The principal value of this graphic exhibit is to show us that the different sorts of animals do not have other sorts for "ancestors." The worms, for example, which are placed higher in the chart than the



The chart in the American Museum which shows the course of evolution of animals, by the special kindness of Dr. F. A. Lucas. The lines do not indicate that animals "descended from" others, but that each sort branched from a common stem. See page 237.



Mendelian inheritance in rats, showing three generations in each group. At the left is a pair of colors: dark, white. At the right is the mixed inheritance of three colors: dark, white, yellow.

jelly-fish, are not "descended from" jelly-fish. The fact seems to have been, as the chart shows, that the different forms of life have kept budding off into branches, which have divided into further branches. The squirrel, perched at the top, did not "descend from" some fishes that are below him; he is one of the latest twigs that come from a branch that came from a limb that grew from the common trunk. If human beings were to be placed in the chart, they could not be shown as descendants of any animals now living, but only as a twig from the "primate" limb of that common branch from which all mammals spring. All animals must have a common ancestry, but seldom is one kind known to have sprung from another kind. Though it is commonly said that birds developed from reptiles, it might be truer to say that birds and reptiles have descended from some common stock.

The bottom of the trunk is labeled "Protozoa"—that is, one-celled animals. Science does not know anything about the roots of this tree—the origin of life—and probably never will know anything. It does not know, with mathematical assurance, that the earliest form of life was one-celled. But it finds all the evidence pointing in that direction and makes the supposition until some contrary evidence appears. Science does not know positively that the first step of evolution was when two cells varied in such a way that they could live to better advantage in partnership; but science finds indications that such was probably the first step. Science supposes that, by a series of variations, many cells came to live in a partnership, forming a sort of colony. It is likely that these cells varied in diverse ways so that some became better adapted for obtaining food, some for digesting it, some for distributing it. When these several sorts of cells had become much differentiated, they were

no longer able to live separate lives; each sort was dependent on all the other sorts; and thus the earliest many-celled animals are supposed to have evolved.

That sounds somewhat fanciful. Perhaps the idea would have remained a pure speculation if we had never known anything about sponges; but among these we can see many stages of just such a process. There are sponges which seem to be mere colonies of similar and independent cells; other sponges in which the cells are highly differentiated and utterly dependent. In this case, as in every other part of the evolution chart, the biologists have not built upon their imaginations, but have always laid foundations upon facts now observable in nature.

Above the sponges the chart shows a branch of such salt-water animals as jelly-fish and sea-anemones. At this point the needs of saving space and avoiding complexity have made the diagram misleading; for the jelly-fish have continued to prosper ever since their ancient beginnings, and their line deserves to be extended to the same height where birds and frogs are displayed. A complete chart of evolution would show, from bottom to top, in what geologic period each type of animal arose, and would continue its line upward till it became extinct or reached the height of the present time. This chart, more convenient and graphic, indicates only how each type branched from the stem.

Two main branches of many-celled animals are shown. The one at the right has ramified into a far greater number of types than the other—from several sorts of worms and mollusks to squids, crabs, spiders, and insects. Most of these are small animals; but one, the giant squid, is large enough to give a whale a tough fight.

At the base of the left branch are certain worms,

and just above these some "radiating" forms, like starfish. From here up all the types tend to a "vertebrate" form—that is, having a backbone. They did not descend from worms or starfish, but from the same parent stock that gave rise to worms and starfish. So, as we look higher up, we are not informed that reptiles descended from fishes, but only that reptiles and fishes grew out of a common stem.

It staggers imagination to see the results of ages of the evolution of structures put thus abruptly before us in a disjointed series. We can not see how the gaps could be bridged. When we learn that the scholars themselves disagree about particulars, and that sometimes they imagine linking forms which they have never seen, we are excusable if we give a verdict of "not proved."

Indeed such an exhibit of successive structures through a long development may misrepresent evolution to us amateurs, for it implies that scientists have relied on a lot of clever conjectures. The truth is just the opposite. The unfilled spaces in the chart of evolution have always seemed more incredible to a biologist than they do to us. He knows how imitative nature always is and how the origin of a new bone is a prodigious work for her mechanism; he marvels at the ease with which college students can take it all on trust and repeat offhand, "Oh, yes, the leg evolved from a fin." It is the scientist who sees that the gaps are extraordinarily hard to fill. It has always been the keenest scholar who has felt most dubious about the successive steps of the evolution of a limb or other organ. He has never accepted surmises and guesses. He has had to be convinced by an unanswerable array of facts.

The study of structures is called anatomy, and the study of the similarities in the anatomy of different

animals is called comparative anatomy. The more science learns about comparative anatomy, the more it discovers those same *continuous series* that are so striking in the geological record and in classification. The student of anatomy knows of finely graded forms from the limb of a lizard to the wing of a swallow, from the fin of a shark to the leg of a lion, from the smooth skin of a whale to the shaggy coat of a bear. The two ends of any such series of structures seem incredibly remote from each other. Every scientist of the nineteenth century, confronted with the extremes and asked to believe that one evolved from the other, was infinitely more skeptical than you and I can be; for he knew how distinct they are in the departments of nature's workshop. Until he saw a demonstration of many actual steps in an anatomical series, he never credited the evolution of one from another.

Imagine that in 1855 Darwin had said to some young man who was beginning the study of zoology, "The hoof of a horse must have developed by gradual continuous stages from the fin of a fish." Imagine the amazement of the young man. If he had lived till 1920, keeping himself abreast of the times and following each advance in zoology, he would slowly have learned—always against his will and his strongest prejudice—that there is no escaping Darwin's conclusion. It is now impossible for the comparative anatomist not to believe it.

An outline of what the young man would have learned begins in the rocks. In the geological period before the coal began to form a lizard-like amphibian one day walked on the hard mud of a river delta where western Pennsylvania now is. His foot, about three inches long, was divided into two principal parts, but there was a bunchy third toe and a slight swelling

corresponding to a fourth toe. One of his tracks was covered in such a way that it was preserved while the mud was transformed to sandstone; and after Darwin died it was discovered by an American geologist and placed in the Yale museum. It is obviously the print of an amphibian's foot, padded and creased and unmistakable. It is the most ancient record ever discovered of any animal that went on feet. Above this stratum of rock there are, in all parts of the world, animals with five toes.* When these are classified in time order, they are found to branch into many kinds, which can be charted in different lines of descent. One line comes down unbroken to modern turtles, another to lizards and snakes, another to crocodiles. Two other lines can be traced to queer species that are all but extinct to-day, one of which is the duck-billed Ornithorhynchus of Australia. Many of the lines have completely died out. One developed into birds, and one into mammals.

The young zoologist would have had small trouble in believing that all modern reptiles descended from ancient reptiles; a small part of the evidence would have convinced him completely. But birds! That would have been beyond belief for some years. Yet if he examined the structure of the winged reptiles that were found, and if he did not think that nature was making game of human beings, he would have had to believe that birds evolved from reptiles. The facts are patent in the museums of London and Berlin, where he could see animals the size of a crow that are as much like our feathered fliers as they are like the oldest lizards. Photographs can be faked, but these remains in the rocks can not be deceptive—unless Satan has played a practical joke on the geologists.

*For the explanation of this great gap in the evolution of the foot see the next chapter.

The wing of the most ancient bird was, in part, a membrane stretched along the side of the body, like the gliding-planes of the extinct flying reptiles; and it was also like the true wing of a modern bird, supported from the fore limbs and covered with feathers. Yet there were claws on the outer joint; and the head, skeleton and teeth were reptilian. No naturalist would have dared to imagine such a beast; nature made it and preserved two specimens for us to see.

"But what about the feathers?" the skeptic would have asked. "I can see that here really is a form midway between reptile and bird, but how could the scales change? You don't show me any steps in the evolution of such an extraordinary structure as a feather. Am I asked to guess that in some vague way each scale grew longer and frayed itself out into tens of thousands of perfectly adapted barbules?"

That is what he was asked to believe. Surely he might well have refused, since he had been taught to think of a scale as a fixed kind of structure, and of a feather as another kind of structure. But if we devoted a year to the study of each, we should find that some fish have scales that are "like hair or feathers,"* that the feathers of the cassowary are very simple structures compared with what we know as feathers, and that in young birds there is a coming and going of feathers such as we never see in any adult bird. We should learn that there is nowhere any hard-and-fast line to be drawn among all the forms that the coverings of vertebrates take: nails, skin, hoofs, scales, shells, plates, plumes, hair, down. We may go all the way along a series of structures from microscopic scales to the horny sections that make up a turtle-shell. Long familiarity with this blending of the different

*Press report of William Beebe's expedition to the Sargasso Sea, March 7, 1925.

structures that grow from the skins of animals would make it hard for any one to believe that they had separate origins; for they seem all related and essentially similar.

Thus the young zoologist would have grown to believe that undoubtedly birds evolved from reptiles. Not that the few indications here given would teach him—far from it—but that in his studious life he would encounter the hundreds of similar links in the chains of evidence that scientists are forever discovering. Bare logic would not be effective; a few dozen probabilities would not persuade him. But the multiplied examples as the years went by would create an unshakable conviction.

As for the descent of mammals from reptiles, it is just a repetition of similar evidence from many series of structures: the order of the fossils and the rare animals still surviving in some corners of the earth give an indication that is irresistible. A student of comparative anatomy learns that there is no hard-and-fast line between reptiles and mammals—not even among the animals that now live. Perhaps to me in my ignorance there seems to be an unbridgeable difference between laying eggs and bringing forth young alive. But the biologist knows of a gradation from one kind of bearing young to the other kind: an egg may be hatched outside of the body, or it may remain within the mother till it is hatched, or it may remain attached to the mother till it has partly developed. Some fishes and snakes bring forth their young alive. The biologist gives the same name to the egg of a snake and to the egg of a sparrow and to the egg of a rabbit; he can not distinguish sharply between the different kinds; he can not conceive that they come from different sources; all his evidence shows that each mode of bearing young was developed from some preceding mode.

The early mammals were small. Apparently they developed in many races through long ages, picking a living as best they could by keeping out of the way of the huge reptiles that dominated the life of the world. If our zoologist kept pace with the fossil discoveries, he might have been convinced of this before 1880. But if any of his early doubts then remained he might have said, "It is too much to ask me to suppose that from a five-toed animal a few inches high there should develop an animal five feet high that walks on a solid hoof. There is no evidence for such profound alterations." Yet most geologists of that time believed that such had been the history of the horse, and they confidently expected that the proof would some day come out of the rocks. It came. There was a find of a small three-toed horse; and another that was smaller, with the side toes longer; and another that was smaller still. One day the news flashed over the wires that a four-toed horse a foot high had been found. Now a series of horses has been set up in a museum,* showing graphically the actual progress of teeth and limbs as they changed and enlarged and took different proportions, from little twelve-inch *Eohippus* to a racing thoroughbred. Similar series are now known for camels and elephants.

The experience of this one zoologist represents the course of scientific opinion since 1860. Then evolution was seen at once to be a shrewd and likely hypothesis, but the gaps in the series of structures were so many and so great that few geologists could expect them to be accurately filled. Every decade has made some remarkable contribution to the evidence, and this steady accumulation which has always fulfilled proph-

*The original series, which Huxley viewed with so much delight, was collected for the Peabody Museum at Yale by Professor O. C. Marsh.

ecies and never disappointed them, has converted the hypothesis into an axiom of zoology.

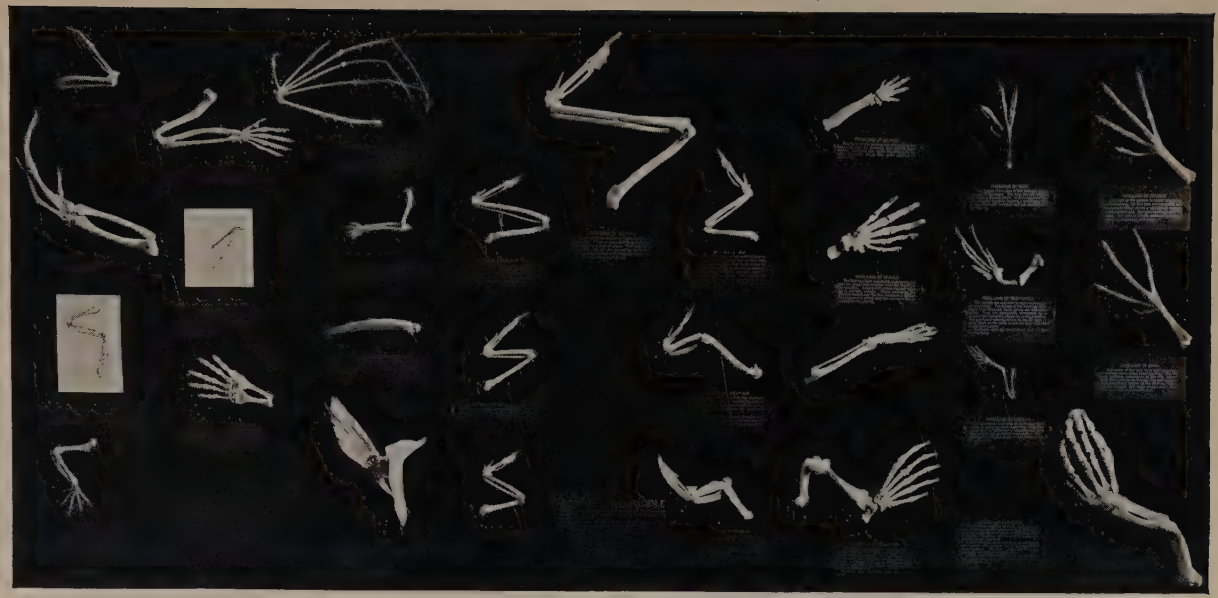
You may be wondering why a chapter on structure keeps talking about the geologic record. "Why," you ask, "must geology and anatomy be mingled in this way?" The answer is that the subjects are inseparable, as can be illustrated from the life of Huxley. He took a medical degree at the age of twenty, studied marine zoology till he was twenty-five, and at the age of twenty-seven, when he first met Darwin, had small faith in evolution. To him, as a student of structures, the gaps between the different classes of animals were too great to be bridged by any theory of common descent. He believed that even species were unchangeable forms of life. If he had never encountered any evidence outside his own field, it is probable that he never would have accepted Darwin's theory. But the fossil record was pointed out to him, and then he realized that the most incredible links of succession were actually to be seen in nature's museum. His judgment of structures had to yield to the knowledge that paleontology put before him. When he based his anatomy on these facts, he found that baffling mysteries were cleared up, and that his study of structures could safely be built on the new foundation. And this, mind you, was long before the discovery of the reptile-like bird or the series of fossil horses. Huxley expressed his debt to geology thus: "The primary and direct evidence in favor of evolution can be furnished only by the fossil record."

I suspect that even the combination of paleontology and anatomy would not have been absolutely convincing to the young zoologist whose career we have been tracing. I can guess that, if he was at all like me, he would not have surrendered till he had learned of the entirely different line of evidence that is explained in

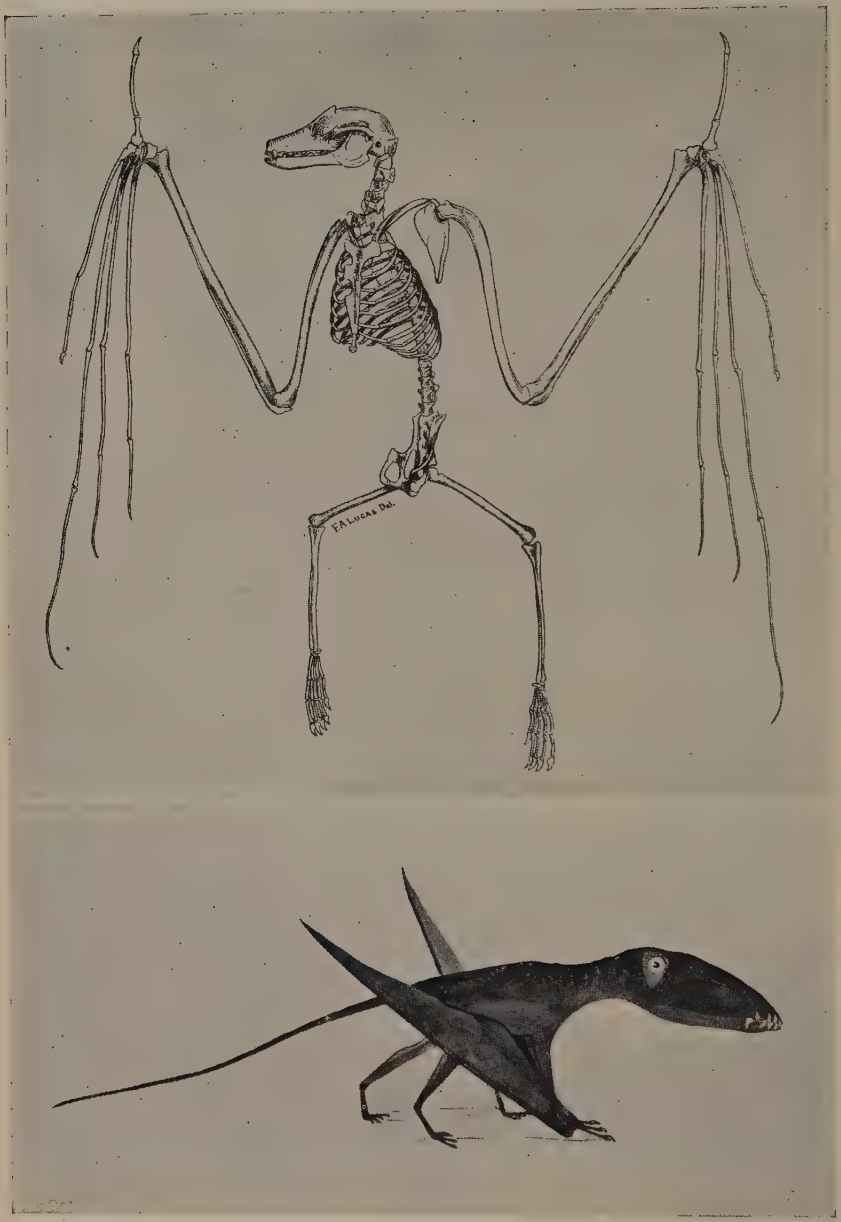
the next chapter. The structures of animals, taken by themselves, might not have seemed a proof; they link together and complete the evidence that is in the rocks and the evidence that is in embryos. As you read the rest of this chapter about structures, bear in mind that it is going to be supplemented in an extraordinary way.

Consider one of the simplest cases of evidence from structure. If we make a list of all the animals that have five digits at the ends of their limbs, we have reason to suspect that they are all related. The way those five fingers or five toes appear in so many guises among the vertebrates, but nowhere else in the animal kingdom, is remarkable. How could it happen —as a set of unrelated accidents—that a panther and a mouse and a frog should have their feet built on the same five-toed plan? The front limb of a bat looks like a five-fingered hand with enormously long bones, one of which extends beyond the wing as a claw. A seal has no apparent use for bones in its flipper—for fish swim faster with no bones in their fins, and seven bones or seventeen bones would make as good a frame for a flipper. But, no—the seal has the same five fingers. The structure of a whale's fin is utterly unlike that of any fish; it is an arm—for there is a big bone at the top, then a pair of bones, then a wrist, and then five digits, one of which is shorter, like a thumb. It can hardly be an accident that so many backboned animals have at the ends of their limbs a hand-like structure—no matter whether they live on land or sea—while no other phylum of animals has anything of the sort in its anatomy.

If this five-finger structure is studied, it is found to be wonderfully prevalent, though in all sorts of disguises and concealments. In the wing of a bird, though the limb structure has been modified almost



If the five-finger structure is studied, it is found to be wonderfully prevalent, though in all sorts of disguises and concealments. . . . In the wings of birds this structure has been modified almost beyond recognition. Page 246.



The five-finger structure in the wing of a fruit-bat, above. Compare this modern apparatus with one of the earliest of Nature's efforts to make a wing. From Seeley's *Dragons of the Air*.

beyond recognition, there still remain three little bones of the five of the original foot; and a rudimentary fourth one has been seen in embryos. In the bird's foot there are three prominent bones (the "metatarsals"), one small one, and the *stunted remnant* of a fifth.

Here we have opened up a whole new realm of structure. We wonder to what extent these *remnants* of bones could be found elsewhere among the vertebrates. They are a regular element of anatomy; so that if we know how to detect them, we can add vastly to the number of five-fingered animals. In fact the student comes to feel that any number smaller than five is abnormal and must be the result of a loss at some time in the history of any modern species. He calls these undeveloped parts "vestigial," for they are vestiges or slight remains of what was once full-grown.

A whale is an exhibit of many remnants of structures that are of no use whatever to it, though they are highly important to the land-living mammals in which they are fully developed. Buried in the body of some species of whales, detached from the backbone, floating in the flesh, are some small remains of legs. They are at the point where a pair of hind paddles would naturally be. And in some snakes the same vestiges of legs appear. In the seal's body the corresponding bones have a strong development—into a regular leg-like series of thigh, lower leg, ankle, foot, and toes—to form the frame of the hind paddle. The only vestiges of hair on a whale are a few bristles near the mouth; the fur seal has the finest coat of hair in nature. The bones of the head of a whale are not the bones of a fish, but strictly those of the land-dwelling mammals; the skull of a seal is still nearer to the land-dwelling type. One kind of whale has true mammalian

teeth, but so vestigial that they never come through the gum; the seal's teeth are strong and useful.

An ingenious naturalist who speculated on seals and whales could note that a seal, which spends much of its time on the land, is more land-like in structure (as shown in a dozen ways other than the hind limbs and teeth and eyes and ears), though it has much of the fish-like form. He could note that a whale, which never lives on the land, has almost entirely a fish-like appearance. Then he could hazard a guess that in some past age certain four-footed mammals found good hunting in the ocean, that every slight variation in structure which fitted them to move better in the water and to stay in it longer was useful and was selected to survive, and that thus there was a gradual adaptation to sea life. He could guess that the seals had gone one-fourth of the way toward complete sea life, and the whales about ninety per cent.—for the whales must still come to the surface to breathe air. If such a supposition about structures stood all alone in the world, it would be no more than a probability till other series of structures had been studied.

Some wings form such a series. It begins with squirrels which can make longer leaps because they are helped by an expanse of skin stretched along the body and held out as a gliding-plane between the legs. Many animals of very different kinds—from squirrels to fish—are helped in their motion by a similar device. Such a membrane is most completely developed among the bats, where it is supported on the excessively long fingers and is like a webbed hand. The extreme of the series is the feathered wing stretched along the whole arm. Other wings form a series that is an entirely different piece of architecture—a membrane supported on extended ribs. A third type of architecture is the wing of all the insects, which is not sup-

ported on limbs, but is an entirely different kind of outgrowth from a different element of the body.

When all the wings of animals are thus assorted into three groups of structure, it appears that the second is rarely seen. The first is the one that has been developed in two lines: the feathered arm-wing of the birds, the hand-and-leg membrane of the bats. The third has branched in the most extraordinary and successful ways among the wasps and flies and moths and bugs. Each type of wing shows a series. Each type of structure appears, when all are charted, to be a well-defined pattern which goes off at an angle from the other types. As we trace them back in time, we can see the similarity of their origins—that is, as outgrowths of the body-covering that were somewhat useful for aiding motion. We can see how each sort radiated farther from the other sorts in the course of ages, like the spokes of a wheel. But we never discover, in wings or in any part of anatomy, that the lines ever come together again.

If all the structures for seeing are classified and charted, they fall into three distinct types: the eyes of vertebrates; the eyes of mollusks; the eyes of insects. The first type of structure is found among all fishes and reptiles and mammals; every form is only a slight variation of the one architectural type. Nothing like the first type is ever found in insects or crabs or lobsters; nothing of the third type is ever to be seen in squids or snails. It appears that eyes, like wings, can be arranged in lines of structure that had similar origins—that is, in spots of the body that were sensitive to light. We can see how each type passed through a series of changes in a long course of development.

This fact of *series of structures* is observed in every phase of animal life. An armored snail and a pulpy slug appear unlike and unrelated; but the student

finds an unbroken series between the two extremes, through smaller and smaller shells, to a mere vestige, to a rudiment under the skin, to no trace at all. The heart of an ox is unlike the heart of a shark; yet, though they are such different structures now, we must suppose that there is a line of descent to a common origin. So we could fill page after page—and great volumes have been filled—with these examples of the series that comparative anatomy has discovered. A dozen series would prove nothing; a hundred would make us suspect; a thousand would suggest a strong probability. When the students of anatomy find that in every respect the structures of all animals are always arranged in such ways that they could have been developed by inheriting variations, they feel almost persuaded. After they have searched a hundred years for some other reasonable explanation of the structures and have found none, then they are convinced.

The whole study of structures fits in with the results of classification. An example is the eye of a hawk and the eye of an octopus. These animals had to be classified in entirely different phyla—that is, in the most widely separated groups, profoundly unlike in organization. Yet their eyes were remarkably similar: each had cornea and lens and retina. This was perplexing; it seemed as if the evidence from structure was at odds with the evidence from classification, and the early skeptics about evolution made much of the argument. But their own reasoning proved that they were wrong: the eye of an octopus, for all its similarity in appearance, is built by a different portion of the body, and is, in its origin, very different from the hawk's eye. As in this case, so in all others: the two kinds of evidence never have failed to support each other. The evidences of struc-

ture have never been made doubtful by the facts of the fossil record, but have in the most complete manner always been vindicated by the fossils. The three kinds of evidence, which are quite independent of each other, check perfectly.

The evidence from structure is the kind that is least understood by general readers. The ordinary way of thinking about evolution is shown in the question, "How could a snake be changed into a turkey?" Each of these animals is at the end of an extremely long line of development. It is like a topmost twig of a branch on which some lower limbs have died and some have branched into varied forms. The evolution of forms never leaps across from the end of one twig to the end of another. Evolution is always a branching from below. If the student of structure follows *back, down* the tree of life, from the twig of snakes, he will come to a certain reptile stock; and if he follows *down* from the twig of turkeys through the branch of modern birds to the limb of ancient birds, he will come to the reptile stock that gave rise to snakes. He does not *want* to do this; he has no "will to believe" it; he knows full well that many a part of the tree of life is undiscovered. But when he is thoroughly acquainted with all the lines of development of structure—from the short and obvious ones to the far-reaching and baffling ones—he has no option but to believe that every species of animal which exists came originally from a common ancestry in a very simple form of life.

Or perhaps it would be more correct to say that he suspends judgment until he learns about the evidence that is seen in the development of eggs, and then has no option but to believe.

CHAPTER XVII

THE EVIDENCE FROM EMBRYOS

A CRITICAL reader of the previous chapter may have noticed one point at which I seemed to slip hastily over a dubious description—the account of the earliest fossil footprint: "His foot was divided into two principal parts, but there was a bunchy third toe and a slight swelling *corresponding to a fourth toe.*" The description passed quickly on to the five-toed reptiles, and then to the wide development of the five-toed foot among mammals. Thus it implied that reptilian feet were evolved through a three-toed and a four-toed form. No evidence was offered of any knowledge that this actually was the course of evolution.

No evidence could be offered in the previous chapter, because none has been found in the rocks. Yet no student of fossils doubts that there was such a course of evolution. If he had nothing to rely on outside of his own field, he would be assured. But he has, from an entirely different source, a confirmation of a most impressive sort. It is a form of evidence that clinches all the other probabilities so completely as to seem almost uncanny when any person first hears of it. It is furnished by the microscope, from observations of what takes place in eggs while they are hatching.

If you could look through a biologist's microscope at the developing egg of a mud-puppy (a little, smooth-skinned, lizard-like salamander), this is what you

would see. The single cell divides into two; each of these two divides into two others; and the process continues until there is a globule composed of a great number of cells. In its next stage the egg becomes a hollow globe. During the third stage one half of this globe bends inward, while the other extends itself around the bent-in part, and there results another globe with an inner and an outer layer. Now the embryo seems to be really under way. What follows has been described by Huxley in words of almost poetic enthusiasm: "The plastic matter undergoes changes so rapid, and yet so steady and purpose-like in their succession, that one can only compare them to those operated by a skilled modeler upon a formless lump of clay. As with an invisible trowel, the mass is divided and subdivided into smaller and smaller portions, until it is reduced to an aggregation of granules not too large to build the finest fabrics of the organism. And then it is as if a delicate finger traced out the line to be occupied by the spinal column, and moulded the contour of the body, pinching up the head at one end, the tail at the other, and fashioning flank and limb into due salamandrine proportions, in so artistic a way that, after watching the process hour by hour, one is almost involuntarily possessed by the notion that some more subtle aid to vision than a lens would show the hidden artist, with his plan before him, striving with skilful manipulation to perfect his work."

The embryo that Huxley described has at first only one toe. After a few hours this has swelled and shows three slight protuberances. These grow steadily more distinct, until the one at the end and the one at the right look almost like pulpy toes. Now the third toe (the one at the left) protrudes more and more, and later there is at its lower left side a fourth

swelling; this becomes a well-extended fourth toe. Finally from the lower left side of this fourth toe grows the fifth stubby toe. By this time the second and third ones have doubled their length, and there is your salamander foot with its five digits.* The steps that were conjectured from the order of the fossils are here visibly reproduced in nature's moving picture, the development of an egg. A record in the rocks, which extended over millions of years of slow evolution from species to species, is here rehearsed† before our astonished eyes in a few hours. It is as hard to believe that the two records are not related as it would be to believe that the White House and a photograph of it were accidental similarities.

What was conjectured about the evolution of the parts of animals, as this was judged simply from the comparison of their structures, can be seen as the minutes go by while we gaze at the building of a body in an egg. It was hard to see how an extra toe could "just somehow sprout" from a three-toed foot; and, indeed, we may never know *how* it could. Yet in the making of every individual salamander the fourth toe, and then the fifth toe, do sprout. The fact of millions of years of evolution of a race is written for our skeptical eyes whenever we watch the "invisible trowel" form a foot in an embryo.

More difficult still is it to imagine how in the evolution of such a complicated creature as a lobster the claws and feelers and legs were ever derived from a

*Description after Lull, from Rabl.

†This "recapitulation theory" was much overworked previous to 1910, and was extended with enthusiasm to help in the harder parts of classifying. Hence some distrust of it arose. This was put very strongly in the old *Britannica* article by Driesch, and echoes of the caution are heard in recent texts. "But," says Professor W. B. Scott, "none of the criticisms denies, and many strongly affirm that embryology affords some of the strongest and most convincing evidence in favor of the evolutionary theory."

set of those simple and similar segments into which the primitive body of its ancestors was divided. Perhaps we shall never learn *how*. The fact that there must have been such evolution through long ages is brought home to the observer of the shaping of any embryo lobster. Let Huxley tell in his vivacious style what he once saw under his microscope:

Our lobster has not always been what we see it; it was once an egg, a semi-fluid mass of yolk, not so big as a pin's head, contained in a transparent membrane, and exhibiting not the least trace of any one of those organs whose multiplicity and complexity in the adult are so surprising. After a time a delicate patch of cellular membrane appeared upon one face of this yolk, and that patch was the foundation of the whole creature, the clay out of which it would be molded. Gradually investing the yolk, it became subdivided into segments, the forerunners of the rings of the body. Upon the surface of each of the rings thus sketched out a pair of bud-like prominences made their appearance—the rudiments of the appendages of the ring. *At first all the appendages were alike,* but, as they grew, most of them became distinguished into a stem and two terminal divisions, to which, in the middle part of the body, was added a third outer division; and it was only at a later period that, by modification, the limbs acquired their perfect form.

Thus the study of development proves that the doctrine of unity of plan is not merely a fancy, that it is not merely one way of looking at the matter, but that it is the expression of deep-seated natural facts. The legs and jaws of the lobster may not merely be *regarded* as modification of a common type; in fact and in nature they *are* so, the leg and the jaw of the young animal being at first indistinguishable.

These are wonderful truths, the more so because the zoologist finds them to be of universal applica-

tion. The investigation of a polyp, of a snail, of a fish, of a horse, or of a man, would have led us to exactly the same point. Unity of plan everywhere lies hidden under the mask of diversity of structure—the complex is everywhere evolved out of the simple. Every animal has at first the form of an egg, and every animal and every organic part, in reaching its adult state, passes through conditions common to other animals and other adult parts.

It is impossible for Huxley, or for any man of mental keenness, to remain scientifically prosy when he states the fact that "every animal and every part passes through conditions common to other animals and other adult parts." No creature, in its early stages, has the outward look of its species—no, not even of its great class or sub-kingdom of animals; it is, so far as human eyes can see, at first a single cell, then a colony of cells, then a folded creature within an inner and an outer layer. It is true, in a very general way, that the embryo of every animal progresses up the scale of lower phyla to that point of advance where its limit lies; it emerges from the embryo to be a lobster, or to be a fish, or a reptile, or a bird.

It would appear as if nature could not originate any novel way of bringing an animal to maturity, but always had to follow the ancient process that she learned with great slowness in the course of long ages, while the higher races very slowly evolved. What she learned to do in the early eras of life she can now do with rapid ease, so that the lowest stage of any embryo is gone through with in comparatively short time; and as the limit of development of any embryo is reached, its processes take longer. It would seem, if we continue this comparison with an artisan, that nature has learned many short cuts in the steps that took her so long while she fashioned

the changing races. At any rate, our eyes can not see all the steps as we observe a developing egg. The early ones seem hurried and huddled together; there seem to be quick jumps over gaps; and there are combinations of processes that probably never were in adults, but have been invented for use in embryos. Hence the history of all ancestors is not told fully and clearly in the egg. What can be seen, especially of the older parts of the line of descent, is a distorted and transformed history. But a history it is. Many of the chronicles of descent are there under some guise or other. The development of every individual is a partial and blurred "repetition" or "recapitulation" of the long development of the race. Hence the facts of the development of embryos are expressed by the name "Recapitulation Theory."

What happens when a hen sits on her eggs, as every encyclopedia now tells us, is this: a fish-like animal appears, with gills and a long tail; then legs bud at four points, and there is a lizard-like animal; the fore legs develop rapidly into wings; the hind legs become chicken legs. The record of tens of millions of years in the rocks is rehearsed here in three weeks. When the ovum of a pig begins to develop, it is hardly to be distinguished from the early stage of a chick, for it looks like a fish; then its legs bud—not pig's legs in appearance, with a cloven hoof, but legs that resemble a lizard's; the fore limbs and the hind limbs develop into pig's legs. The embryo of a rabbit seems to be a fish and a reptile before it becomes a rabbit. Every mammal, in its own life, lives rapidly through the stages that cover such stupendous ages in the rocks. If John Doe is curious about his own evolution, he should read an encyclopedia article that describes the stages through which he himself lived during the first months of his life.

The revelation of race history that comes from embryos is of a kind that rivets attention. It is startling and romantic to the last degree. The nature of it may be put into graphic form thus: An English surveyor goes tapping about the hills with his hammer, never dreaming of evolution, and as he pieces together the facts in the rocks they spell out before his astonished eyes a history of an order in which animals succeeded one another while the different rocks were formed. In a laboratory of northeastern Prussia a Russian scholar works month after month with his microscope; through the lenses there swims into his ken, as the egg develops, the history of the same order of succession. The testimony of the rocks and the revelation from the egg coincide.

Long before the *Origin of Species* appeared, the embryologists had seen the stages of development in eggs. One of the greatest of them used to exclaim as he showed his specimens, "I have here the embryos of lizards and pigs and rabbits, but I can not tell which is which. They are all alike." Until 1859 there was no meaning to these facts. Then embryology took a fresh start, and it began to contribute to evolution.

The first actual demonstration that embryos and rocks tell the same truth was not made until 1869. In that year a German named Waagen published his observations of three species of coiled ammonite shells—the kind that Holmes addresses in his *Chambered Nautilus*. Waagen found in three successive strata the three species arranged, of course, in the order of their evolution. Many of the specimens were of half-grown shells, and of shells only in infancy. A study of some of the undeveloped shells in the top stratum showed that they resembled the mature shells of the earlier species in the stratum next be-

low; and a study of shells still less developed proved that they resembled the oldest species in the lowest stratum. Nature had arranged in this series of rocks a display of embryology, a demonstration that every shell in its individual life had gone through just the changes that the race of shells had gone through in the three strata. No more precise or sensational sort of proof was ever known to science.

The life histories of all sorts of animals have been studied with most painstaking scrutiny. There have been able embryologists who would have given all they owned to prove that the development of an egg does not parallel the fossil record, and they have argued and protested with vehemence. So startling a correspondence between two such different departments of science is unique, and the reasoning about it has been subjected to a long and fierce test. The recapitulation theory has stood the test. No evidence from the microscope collides with any evidence from the fossils. In many striking and conclusive ways the microscope has shown zoologists how to classify; but it has never given evidence counter to the principles of classification. If the combination of the fossils and the embryos is not a proof, then the universe is a whirligig and man's reason signifies nothing.

It may perhaps be conceivable by some minds that the records of rocks and eggs merely happen to have a resemblance. Possibly some intellects can suppose that all nature was planned as a temptation, to deceive the minds of scientists by a coincidence that means nothing. We can not prove that a Creator might not have paralleled the embryos and rocks in a fit of humor. Evolution can not be demonstrated. But every modern scientist, aware of how serious and uniform nature always is, must reject any such evasion of evidence. There is nothing for any logical mind to do but to accept the Evolution Theory.

CHAPTER XVIII

THE EVIDENCE FROM BLOOD

The chapter on the structures of animals was limited to the large and noticeable features of the body, such as bones and organs. It could have been extended to all the minute portions, like the fluids and cells that carry on the life processes. For just as nature follows one architectural pattern for limbs and eyes in each sub-kingdom of animals, so for each small matter of physiology she keeps to a general similarity throughout the whole of a group. Take the blood as an example. We should suppose that the warm blood of a bird was more like the warm blood of a mammal than the cold blood of a turtle. But this is not so. For birds are of the reptile stock, and every corpuscle that carries oxygen to their tissues is made on a reptilian pattern—that is, it has a nucleus, and is a true cell. The full-grown red corpuscle in a mammal's blood has no nucleus. Hence a biologist could tell by a glance through his microscope whether a sample of fresh blood came from a lower vertebrate or a mammal.

The differences in the blood extend to very much finer matters than corpuscles. The chemical components are different. And they do not differ erratically, independently, but always in correspondence with the general structure of the phylum and class and order and family. If we had instruments fine enough to detect all these slight and orderly dif-

ferences there is no doubt that a mere examination of a specimen of blood would show from what genus it came, and from what species. Every particle of blood is compounded by the recipe that fits its particular species, a recipe that is unlike the formula for any other species. These distinct and precise differences that must be in bloods was somewhat understood forty years ago. In 1904 an elaborate treatise on the subject was published in England, called *Blood Immunity and Blood Relationship,* which explained a most accurate and far-reaching method in physiology.

The knowledge of blood relationships has furnished the latest kind of evidence for the detectives who seek the clues to evolution. It is evidence from an unexpected source, entirely independent of any knowledge that comes from other lines of research. The nature of these "blood tests" and of what they show may be briefly outlined as follows:

If some serum of the coagulated blood of a horse is injected into the veins of a rabbit, the rabbit's blood forms a sort of anti-toxin against the chemicals of the invading serum from the horse. If, now, some serum from such prepared rabbit blood is put into a solution with horse blood, there is a chemical reaction that is well known and unmistakable. But if the prepared rabbit blood is put with ordinary rabbit blood, there is no reaction. In other words, the blood that has bred anti-toxin against the horse serum is a very sure and delicate test for horse blood. The evidence, it should be noted well, is not from living cells or tissues or any form of life: it is from a very different source—from the field of chemical reaction.

The test works so perfectly for human blood* that

*In *Science* for May 8, 1925, is an article by Landsteiner and Miller, of the Rockefeller Institute, confirming and extending the Nuttall tests in a remarkable way.

it can safely be used in murder trials to determine whether or not a stain was made by blood from human veins. It indicates in a very detailed way that the relationship of man to other animals is what the evidence of anatomy and the embryo shows.

A long series of experiments has been made with all sorts of combinations; the result is that "anti-blood tests" are found to be of varying intensity. For example: the rabbit's blood that is "anti-horse" will react against the blood of a mule or a zebra, but less strongly; it will react less strongly still against the blood of a cow or a pig. It is found to be generally true that in proportion as any animal is more nearly related to the horse in classification its blood gives a stronger reaction, and that as the relationships of different animals grow more and more distant from the horse the reactions from their bloods grow weaker and weaker. The chemical evidence is in close correspondence with the evidence from classification and structure.

In fact the anti-blood tests are now well enough understood and tabulated to be used as evidence in clearing up some doubtful points of classification. Anti-pig serum, for instance, will act strongly against the blood of any member of the pig family; it will act much less strongly against the blood of camels and llamas (about equally for these nearly-related animals); and much less still for a whale.

Blood tests have shown that birds are more nearly related to turtles than they are to lizards, and thus confirm in a most curious way what the experts in fossils had conjectured.

How to classify the horse-shoe crab has always been a puzzle. The study of embryos showed that it was more nearly related to the scorpions than to real crabs—an unexpected verdict. Hence the blood-test

men must have felt some excitement when they had perfected their art enough to apply it to this peculiar puzzle. The blood test confirmed the embryos.

What fame would have come to these workers with serums if they could have produced evidence against the rocks or the embryos! Their experiments would have been proclaimed in every scientific journal, and the newspapers would have written them up. They could have sold one hundred thousand copies of a book entitled *Darwin Overthrown by Blood.* But there was no such fame or wealth in store for them. They could do no more than add to the list of evidences which always grow stronger, never infringe on one another, and multiply one another's strength. Every one who has ever learned something new about the life of plants and animals has always—whether he would or not—brought fresh witness to the Evolution Theory.

PART THREE

The History of Evolution

CHAPTER XIX

LAMARCK

Aristotle inferred from his observations that all which now exists—the stars, the mountains, the trees, the animals—has developed into the present forms by a series of changes. This remarkable conception became material for the philosophers, but was never supported by observation; during the Middle Ages it was seldom defended or even mentioned. Up to 1700 it was no more than a general theory of causation—that is, the idea that all changes in the physical world are due to natural causes, not to miracles. By 1760 this theory had been applied particularly to plants and animals by several writers—notably by Buffon. In 1794 Erasmus Darwin speculated about development in these terms: "Would it be too bold to imagine that all warm-blooded animals have arisen from one living filament, which the great First Cause endued with animality?" The general theory of development was in the air, but it remained a vague philosophical conjecture.

In 1809 (the very year of Charles Darwin's birth) a brilliant Frenchman, Lamarck, published his *Zoological Philosophy,* in which he described a theory of evolution that he had been brooding on for sixteen years. Here for the first time evolution was brought down from philosophy to be applied in a particular way to animals and plants. Lamarck was a thorough scholar and a hard worker, who was so well ac-

quainted with the difficulty of classifying species that he felt there could be no hard-and-fast line between them. It seemed to him that somehow the whole series of animals was like a continuous stream of forms that had developed from previous forms. His quick fancy framed a theory to account for such development—briefly this:

Persistent use of any part draws the fluids of the body there, "and in proportion as the fluids are quickened in their movements, they alter the tissues in which they move"; such changes in the body are inherited and tend to accumulate in successive generations.

This theory is based on "the effects of use and disuse" and on the supposition that such effects ("the acquired characters") can be inherited. It was a brilliant bit of imagining, put forth in a small book that could have been written in a few weeks, and it contains few efforts to supply facts in support of the reasoning. Lamarck belonged mentally to the eighteenth century, when it was thought that science could be spun out of an ingenious brain. In his early efforts at science his speculations about chemistry were "of a chimerical kind," and he made "fruitless meteorological predictions." In his latest efforts, when he reasoned about fossils, he poured out from his teeming brain the extravagant guess that all the rocks were made from the remains of animals. From youth to old age his mind was primarily fanciful.

Yet he was much more than a wild fancier. His eyes were sharp and his intuition quick. However flimsy his reasoning might be, he had keen powers of perception. What he thought out he could express in a cogent and lively style. His book set the scientific world all agog. Its influence was strong for half a century—yes, for almost a century—captivating many

trained minds. Its teaching could not be disproved by any facts that were then known to science, and it was so much in line with the natural suppositions about heredity that even Herbert Spencer espoused it and argued for it all during Darwin's lifetime. In fact the teaching of Lamarck has not yet ceased its effect.

The reason for this influence is not difficult to see. Lamarck had perceived a great fact that was hidden from all slow and conservative minds—to wit, that a species is not a fixed form of life, that there is no telling where one species ends and the next one begins. That is a great truth, and it is Lamarck's glory that he saw it and put it vigorously before the world. What is more, no one could offer any substitute to improve on Lamarck's reasoning. His theory split the naturalists into three camps: those who followed him in believing that species changed by inheriting acquired characters; those who believed that species did not change by any process; those who thought that possibly species did change, but by some process that had not been discovered. If any intellectual man was imaginative and had no special knowledge of animals, he was likely to belong to the first camp and be a Lamarckian; if a man was a hard-headed specialist familiar with facts, he was likely to belong to the second camp; if he was an exceptionally thoughtful naturalist, familiar with the difficulties of classification, he would have leanings toward the third camp. The great majority of scientists belonged to the second group—at least after 1840, when the spell of Lamarck had begun to wane. Two examples will show this. Weismann says that when he was a young student in Germany during the late fifties it was bad form scientifically to take any stock in an evolution theory. When Huxley was a young

man and first met Darwin about 1850, he made the remark which he felt sure was the correct thing to say to a great scientist: "I believe that species are immutable." Thus Lamarckism was tried in the balances for half a century and found wanting.

Any sketch of the history of the Evolution Theory should at this point repeat in italics the principal feature of all discussions before 1859: *No one disputed the possibility that acquired characters could be inherited.* This was one phase of that question which has always been paramount and which is not yet settled—"What is variation?" Lamarck assumed—all scientists assumed—that variation is the alteration produced in the body of an organism by use or disuse or by changed environment, and that such alteration is inherited. The eyes of all the disputants were turned to acquired characters. And to what else could they turn? There was nothing else in sight.

CHAPTER XX

DARWIN

The son of the Erasmus Darwin mentioned in Chapter XIX settled in Shrewsbury, built up a large practice, and became well-to-do; but he inherited no acquired theory of evolution. He named his fourth child, born in 1809, Charles Robert, and hoped that the boy would continue the family tradition by entering the medical profession.

But Charles could not endure the horrors and the dullness of the Edinburgh school of medicine. So at the age of nineteen he was sent to Cambridge to be educated for the ministry. "I liked the thought of being a country clergyman," he says in his autobiography, "and did not then doubt the strict and literal truth of every word in the Bible. Nor was this intention ever formally given up, but died a natural death when, on leaving Cambridge, I joined the *Beagle* as a naturalist." In the classics he had no interest, but in any sort of experimental science, or in the study of insects and birds and shells, in geometry, in Paley's *Natural Theology,* he delighted. A little episode of 1831, just after his graduation from Cambridge, illustrates Darwin's way of regarding science. The Reverend Adam Sedgwick, an able professor of geology at Cambridge, visited the Darwin home on one of his expeditions for examining the ancient rocks. Young Darwin told him of a tropical shell that a laborer claimed he had found in a gravel-pit. Sedgwick

thought that the shell had been brought there by some man, and added, "If it was really embedded there, it would be the greatest misfortune to geology, as it would overthrow all that we know about the deposits of the Midland Counties." Darwin remarks, discreetly and gently, that this attitude of mind produced a strong impression on him. No wonder it did. For here was a man who valued a supposition more than a fact that would teach him the falsity of his supposition. Darwin's mind always worked on the other tack and always prized any fact that would compel him to seek for new knowledge.

Darwin at the age of twenty-two was an ardent sportsman and collector, affectionate, so tenderhearted that he would not take more than one egg from a nest or put a live worm on his hook, modest, reverent, clear-headed, and in rugged health. So good an observer was he and so enthusiastic that the professors of science took special notice of him and predicted a future for him. But his father could see no promise in the career of a son who seemed to care for nothing but shooting grouse and tramping thirty miles a day in the Welsh mountains.

In 1831 a Cambridge professor recommended him for the position of naturalist on board the government ship *Beagle*, which was to take a trip around the world, making soundings for the admiralty charts. Darwin was glad of such a chance to follow his collecting mania, and for five years, without pay, performed his duties enthusiastically. Never was a country better served by any amateur scientist.

A year after his return, in 1837, he settled himself deliberately for an attack upon the great question, "How have animals become adapted to their ways of life?" We can not appreciate the ardor and severity of the twenty years of labor in seeking an

answer to the question unless we form some picture of his manner of life and work. He had inherited a considerable fortune and was free to live a life of ease, yet he chose a life of incessant toil. He conducted all manner of prolonged experiments with seeds and eggs and breeding of pigeons, observing the growth of plants, making minute measurements of bones and teeth, going carefully through great files of breeders' journals and horticultural magazines, reading stacks of French and German scientific books, corresponding with all manner of men who might furnish him information, utilizing his daily walks for observation and experimenting—living every waking hour with the eager purpose of gathering more data. And all this unending labor was carried on against the greatest odds—for after 1837 he never knew a day of the health that had been so bountiful in youth. His digestion had been impaired by constant seasickness during his five years aboard ship; his nerves had been so much injured that even ordinary visiting was apt to excite illness; he was easily fatigued. Every morning he rose early and went to work, continuing at work as many hours as he dared; then he would rest as long as he was compelled to—never a minute longer. While he rested, he listened to reading. Every possible hour of labor was put in during every day of every year. All the skill of a tactful wife was exerted to keep his strength as great as loving care could make it. Until 1842 he lived in the quietest London lodgings to be found, and after that he had a most secluded country home. No human life could have been more completely devoted to one unremitting purpose.

His practical and acute mind had never taken any stock in Lamarck's easy-going answer to the riddle of evolution. He relates how one time when he was

only eighteen years old, as a young medical student in Edinburgh, he "listened with silent astonishment" to an older student who "burst forth in high admiration of Lamarck and his views on evolution." These views he thought were based on a very unsatisfactory kind of evidence. He thus describes his state of mind in 1837, when he began to ponder on his South American observations of fossils and varying species:

It was evident that such facts as these could only be explained on the supposition that species gradually become modified; and the subject haunted me. But it was equally evident that neither the action of the surrounding conditions nor the will* of the organisms could account for the innumerable cases in which organisms of every kind are beautifully adapted to their habits of life. I had always been much struck by such adaptations, and until these could be explained it seemed to me almost useless to endeavor to prove by indirect evidence that species have been modified. . . . I worked on true Baconian principles, and without any theory collected facts on a wholesale scale, more especially with respect to domesticated productions. . . . I soon perceived that selection was the key-stone of *man's* success in making useful races of animals and plants. But how selection could be applied to organisms living *in a state of nature* remained for some time a mystery to me. . . . Fifteen months after I had begun my systematic enquiry I happened to read for amusement *Malthus on Population,* and being well prepared to appreciate the struggle for existence which everywhere goes on from long-continued observation of the habits of animals and plants, it at once struck me that under these circumstances favorable variations would tend to be preserved, and unfavorable ones to

*A reference to Lamarck's "volition" or "appetence" of animals —that is, the inward, unconscious impulse that he imagined directed animals in the line of their development. The idea is not yet dead in the scientific world; see Chapter XXIV, Section II.

be destroyed. The result of this would be the formation of new species. Here then I had at last got a theory by which to work; but I was so anxious to avoid prejudice that I determined not for some time to write even the briefest sketch of it. In June, 1842, I first allowed myself the satisfaction of writing a very brief abstract of my theory in pencil, in 35 pages; and this was enlarged during the summer of 1844 into one of 230 pages.

Even in 1844 he had not fully decided that species develop by a change of previous species, for he said in a letter to Hooker: "At last gleams of light have come, and I am almost convinced (quite contrary to the opinion I started with) that species are not (it is like confessing a murder) immutable."

By 1856 the whole theory was clear in his mind, and he began to set it forth "on a scale three or four times as extensive as the *Origin*"—which is itself six hundred and seventy pages long. Yet even this elaborate work, if he had carried it out as planned, would have been "only an abstract of the materials which I had collected." He estimated that "my notes are so numerous during nineteen years' collection that it would take me at least a year to go over and classify them."

In June, 1858, his work was interrupted by a most extraordinary letter. It came from a naturalist in the East Indies, asking Darwin to read an essay that was enclosed—an attempt to explain how species originated. If ever a letter was a thunderbolt, that one was. It was the most extraordinary coincidence in the annals of science, and all the events that led up to it multiplied the wonder of it.

The naturalist who wrote it was Alfred Russel Wallace, an Englishman fourteen years younger than Darwin, whose life had been somewhat similar. At

the age of twenty-five he had gone on a collecting trip to the Amazon, and a few years later sailed for the Malay Archipelago, where he spent eight years. Like Darwin, he was struck by the bewildering array of new species, of confusing similarities, of difficulties of classification, of remarkable facts of distribution, of the wonderful variety of adaptations for succeeding in the tropical struggle for existence. Like Darwin, he had started abroad with the conviction that a species is an immutable form of life, but this belief waned as it encountered the horde of new facts. In 1855 he wrote an essay arguing that every species has been derived from a previous species. From that time his mind, like Darwin's, was haunted by the question, "*How* could such changes come about?" One day early in 1858, while he was wrapped in blankets during a cold fit of a fever, he fell to ruminating on the same Malthus book that had started Darwin's mind, and he began to consider the effects of the struggle for existence. "There flashed upon me," he says, "the idea of the survival of the fittest." Thus Wallace in his blankets and Darwin in his carriage had seen the same revelation suddenly shine upon them as they stumbled over the same dark road of questioning. "If Wallace had had my sketch of 1842," wrote Darwin, "he could not have made a better short abstract. Even his terms now stand as heads of my chapters."

Here was a very delicate situation. Darwin's priority in reaching the theory was recorded in formal letters and was unquestionable, but he had not published any account of it. He argued that Wallace, if he had been in England, might very likely have published his essay, and so have appeared in the records of science as the first to formulate an evolution theory. This would have been the saddest kind of dis-

appointment to Darwin, a frustration of the ambition that is dearest to every scientist. But conscience told him that he must do for this young man what the young man might have done for himself if he had not put his fame in Darwin's hands. Darwin resolved to have Wallace's essay published, and to concede him the priority without explanation. "I felt angry at myself," he confessed, "for not being able to repress a feeling of disappointment at what I thought was Wallace's forestalling of my years of work."

This extravagant generosity (which would have been unfair to Darwin and a false honor for Wallace) was overruled by Lyell and Hooker, who acted as referees in the strange affair. They agreed to publish Wallace's essay, for that was his due; but only on condition that some of Darwin's sketch of 1844 should be published with it, so that the two men should be linked in a joint report. They argued that they were deciding a question, not simply of the interest of one man or the other, but of the interest of science generally.

This chivalrous handling of the delicate matter by Darwin and his friends is a charming episode in the history of science. Darwin and Wallace were firm friends for the rest of their lives, and Wallace became a useful and powerful champion of what he called "pure Darwinism." He has had his full share of credit—perhaps more; for he never could have established the theory on any such firm foundation as Darwin was able to make for it. He had no such great quarry of facts from which to take building material, nor the power of mind to organize so wide-reaching an argument. His judgment was not of Darwin's unerring quality, and hence he would not have been able to frame such a consistent whole out of the intricate and manifold data. At the Darwin

centenary in 1909 he thus described the relative credit that was due to himself and to Darwin: "My share in the theory is to Darwin's as two weeks is to twenty years." Such genial modesty has endeared him to all the writers on evolution, so that they have been inclined to give him much more credit than he ever claimed for himself. The progress of the theory owes much to the knowledge and skill with which he argued for it.

Darwin pushed forward his *Origin* as rapidly as possible and got the book through the press on November 24, 1859. The first edition, one thousand, two hundred and fifty copies, was sold the first day. His diary records in December, "Multitude of letters." To all his scientific friends he sent copies, and to other scholars whose opinions he valued. With these gifts he sent notes, the tenor of which is shown by the following sentences to Falconer: "Lord, how savage you will be if you read it, and how you will long to crucify me alive! I fear it will produce no other effect on you; but if it should stagger you in ever so slight a degree, I am fully convinced that you will become, year after year, less fixed in your belief in the immutability of species."

How promptly and enthusiastically the best minds of the day felt the strength of the *Origin* has been indicated in Chapter XII. The fear and distrust of the new theory can be shown by quotations from two letters written shortly after its appearance. To John Lubbock, Darwin wrote: "There are so many weighty arguments against my notions that you will easily persuade yourself that I am wholly in error. . . . I dare say that when thunder and lightning were first proved to be due to secondary causes, some regretted to give up the idea that each flash was caused by the direct hand of God." Lubbock did not

feel that such a reason was weighty and allied himself with the Darwinians. But Sedgwick—the man who thought that the discovery of a fact might be a misfortune—wrote thus: "If I did not think you a good-tempered and truth-loving man, I should not tell you that I have read your book with more pain than pleasure. Parts of it I admired greatly; other parts I read with absolute sorrow, because I think them utterly false and grievously mischievous. . . . You write of 'natural selection' as if it were done consciously by the selecting agent.* . . . 'Tis the crown and glory of organic science that it *does,* through final *cause,* link material and *moral.* You have ignored this link. . . . Passages in your book greatly shocked my moral taste. . . . I have written in a spirit of brotherly love, therefore forgive any sentence you happen to dislike; and believe me, spite of any disagreement in some points of the deepest moral interest, your true-hearted old friend."

Sedgwick's fear was exactly what Darwin had prophesied when he spoke of thunder. To many devout minds of the eighteenth century Franklin's experiments with electricity were *morally* disturbing, because Franklin seemed to deny that God directly ordained each clap of thunder. Scores of New England ministers felt that it was irreligious for science to investigate the instrument of God's vengeance, just as scores had formerly felt that the law of gravitation was opposed to religion. Hundreds of ministers in the nineteenth century felt that it was irreligious to describe the adaptations of animals without reference to God's direct ordaining of each one. Now, in the twentieth century, most ministers can see that the fallacy of these two fears is exactly alike. As

*From that day to this the same misunderstanding of Darwin's metaphor has been frequent.

they look back on the periods of distrust, they see the pathos of it and wonder that teachers of religion should have been so blind. Yet we must sympathize with people who were afraid on moral grounds when such reasoning about gravitation and electricity and animals was new.

Darwin's feeling about this religious fear may be gathered from the following sentences of the description which the vicar of Down, the Reverend J. Brodie Innes, gives of his thirty years of friendship with Darwin: "I had adopted the principle that the Book of Nature and Scripture came from the same Divine source, ran in parallel lines, and when properly understood would never cross. Mr. Darwin's views were very much to the same effect. The quaint conclusion of one of our conversations on religious subjects may be given; he said, 'I do not attack Moses, and I think Moses can take care of himself.' To the same effect he wrote more recently, 'I can not remember that I ever published a word directly against religion or the clergy; but if you were to read a little pamphlet which I received a couple of days ago, you would admit that I had some excuse for bitterness. The author, a clergyman, sums up by saying that he has vainly searched the English language to find terms to express his contempt for me and all Darwinians.' "

Some noted clergymen were friendly to Darwinism from the beginning, as shown by Charles Kingsley's letter of 1859, quoted in Chapter XXV. But in the main the church was hostile for twenty years. Most thoughtful leaders of religious opinion must have ceased their attacks before 1900; for in 1894, at a small western college (then denominational), I was taught, both in the zoology class and from the pulpit, that evolution was not in conflict with religion.

It may be that personality has no place in science, but for my own part I find the individuality of Darwin so interesting, and so unlike what might be guessed, that I shall venture to give some idea of it. In 1842 he took his family to a village twenty miles south of London, the hamlet of Down, which was ten miles from a railroad station and so secluded that he could be free from interruption by casual visitors. There he lived forty years, never missing a day of his beloved work unless his health failed. It is safe to say that during those years there was not in England any man whose home life was more beautiful, who was more genial and courteous, more honorable and affectionate in nature, or more devoted to the search for truth.

The following quotations are taken from the sketch that his son wrote to preface a collection of his letters.

He was delightfully tender to Polly, a rough, white fox-terrier, and never showed any impatience at the attentions she required, such as to be let in at the door or out at the verandah window. He was always rejoiced to get home after his holidays; he used greatly to enjoy the welcome he got from Polly, who would get wild with excitement, panting, squeaking, rushing around the room. He used to stoop down, pressing her face to his, and speaking to her with a peculiarly tender, caressing voice.

I used to like to hear him admire the beauty of a flower; it was a kind of gratitude to the flower itself, and a personal love for its delicate form and color. I seem to remember him gently touching a flower he delighted in; it was the same simple admiration that a child might have.

He once [when a boy] killed a hare sitting in the flower-garden at Shrewsbury by throwing a marble at it, and once, as a man, killed a cross-beak with a

stone. He was so unhappy at having uselessly killed the cross-beak that he did not mention it for years, and then explained that he should never have thrown at it if he had not felt sure that his old skill had gone from him.

When he was excited with pleasant talk, his whole manner was wonderfully bright and animated, and his face shared to the full in the general animation. His laugh was a free and sounding peal, like that of a man who gives himself sympathetically to the person who has amused him. . . . To Huxley he once wrote, "For your lectures I can give you a few amusing anecdotes and sentences if you want to make the audience laugh."

I do not believe he ever spoke an angry word to any of his children in his life; but I am certain that it never entered our heads to disobey him. He kept up towards his children his delightful manner of expressing his thanks; and I never wrote a letter, or read a page aloud to him, without receiving a few kind words of recognition.

He drank very little wine. He had a horror of drinking, and constantly warned his boys that anyone might be led into drinking too much.

It is impossible adequately to describe how delightful a relation his was to his family, whether as children or in their later life. It is a proof of the terms on which we were, and also of how much he was valued as a playfellow, that one of his sons when about four years old tried to bribe him with sixpence to come and play in working hours. We used to dread going in for sticking-plaster, because he disliked to see that we had cut ourselves, both for our sakes and on account of his acute sensitiveness to the sight of blood. He always made us feel that we were each of us creatures whose opinions and thoughts were valuable to him, so that whatever there was best in us came out in the sunshine of his presence.

A few days after the death of his little daughter, Annie, he wrote: "We have lost the joy of the household, and the solace of our old age. She must have

known how we loved her. Oh, that she could now know how deeply, how tenderly, we do still and shall ever love her dear, joyous face! Blessings on her."

When he gave his evidence before the Royal Commission on vivisection, he came out with his words about cruelty, "It deserves detestation and abhorrence." When he felt strongly about any similar question, he could hardly trust himself to speak, as he then easily became angry, a thing which he disliked excessively. He was conscious that his anger had a tendency to multiply itself in the utterance, and for this reason dreaded having to scold a servant.

The letters that he received gave him much pleasure, because he habitually formed so humble an estimate of the value of all his works that he was generally surprised at the interest which they excited. His happy choice of matter for talk seemed to flow out of his sympathetic nature, and humble, vivid interest in other people's work.

He undoubtedly had, to an unusual degree, the power of attaching his friends to him.

His relationship to the village people was a pleasant one; he treated them, one and all, with courtesy, and took an interest in all relating to their welfare. Some time after he came to live at Down he helped to found a Friendly Club, and served as treasurer for thirty years. He took much trouble about the club, keeping its accounts with minute and scrupulous exactness. Every Whit-Monday the club used to march round with band and banner, and paraded on the lawn in front of the house. . . . Mr. Innes, the vicar of the church writes: "In all parish matters he was an active assistant; in matters connected with the schools, charities, and other business his liberal contribution was ever ready, and in the differences which at times occurred in the parish I was always sure of his support."

I must say something of his manner of working. He showed his love of saving the minutes in the difference he felt between a quarter of an hour and ten

minutes' work. . . . I was often struck by his way of working up to the very limit of his strength, so that he suddenly stopped in dictating, with the words, "I believe I mustn't do any more." . . . All these processes were performed with a kind of restrained eagerness. He always gave one the impression of working with pleasure, and not with any drag. I have an image of him as he recorded the result of some experiment, looking eagerly at each root, and then writing with equal eagerness. . . . I think he personified each seed that he was counting as a small demon trying to elude him by getting into the wrong heap; and this gave to the work the excitement of a game.

A few of his mental characteristics, bearing on his mode of working, occur to me. There was one quality of mind which seemed to be of special and extreme advantage in leading him to make discoveries; it was the power of never letting exceptions pass unnoticed. It was just these things that he seized on to make a start from. . . . Another quality was his power of sticking to a subject. He often quoted the saying, "It's dogged as does it," and I think doggedness expresses his frame of mind almost better than perseverance. Perseverance seems hardly to express his almost fierce desire to force the truth to reveal itself. . . . He was willing to test what would seem to most people not at all worth testing. These rather wild trials he called "fool's experiments," and enjoyed extremely. . . . The love of experiment was very strong in him, and I can remember the way he would say, "I shan't be easy till I have tried it," as if an outside force were driving him.

The tone of the *Origin* is charming, and almost pathetic; it is the tone of a man who, convinced of the truth of his own views, hardly expects to convince others; it is just the reverse of the style of a fanatic, who wants to force people to believe. The reader is never scorned for any amount of doubt which he may be imagined to feel, and his skepticism is treated with patient respect. A skeptical reader, or perhaps even

an unreasonable reader, seems to have been generally present to his thoughts.

He speaks of all other authors as persons deserving of respect. His respectful feeling was not only morally beautiful, but was of practical use in making him ready to consider the ideas and observations of all manner of people. In spite of having so strong a respectful feeling, he had the keenest of instincts as to whether a man was trustworthy or not. He seemed to form a very definite opinion as to the accuracy of the men whose books he read; and made use of this judgment in his choice of facts for use in argument or as illustrations.

He had a keen feeling of the sense of honor that ought to reign among authors. He had a contempt for the love of honor and glory, and in his letters often blames himself for the pleasure he took in the success of his books, as though he were departing from his ideal—a love of truth and carelessness about fame.

When Darwin died in the spring of 1882, a committee of Parliament petitioned that he should be buried in Westminster Abbey, and the dean gladly assented. Among his pall bearers were Canon Farrar, James Russell Lowell, the Duke of Argyll, and four of the scientists who had revered him, in the words of John Lubbock, "as their dear master."

CHAPTER XXI

WEISMANN

As we pass beyond Darwin's period, it will be well to recall the seven evidences for evolution, in order to see how they fitted into the history of the development of the theory. Lamarck, in 1809, had to rely mainly on the evidence from classification and got hints from the evidence of structures. These could indicate to his lively mind that there had been evolution, but they could furnish no data as a proof. By the time Darwin settled himself to solve the problem there had been great advances in the knowledge of the fossil record and of the distribution of life in geological times and now. Darwin used these as a set of facts which challenged science to explain them, which admitted of no solution except evolution, but which did not furnish any key to the *process* of evolution. That key he found in artificial selection, and with it he opened the gates of the mystery.

But the definite evidence that is in embryos was mostly hidden from him. He could divine its general nature, and he declared in 1860, "Embryology is, to me, by far the strongest single class of facts in favor of change of forms." But further he could not see, for the realm of chromosomes was only beginning to be explored when he died. The knowledge of that field was the next great advance in the Evolution Theory.

While young Darwin was going around the world

on the *Beagle,* August Weismann was born in Germany. He trained himself to be a physician, was made a professor of zoology, and devoted himself to studies with the microscope. So ardently did he use his eyes that they gave out, and for nearly ten years he was practically blind. But he did not allow the loss of sight to interfere with work. He had books read aloud to him; he pondered the problems of evolution, especially those raised by the *Origin of Species;* and he dictated essays on the central problem of them all—the nature of variation. One of the last labors of Darwin was to write a preface for the English translation of these essays, which appeared the year he died. After this ten-year period Weismann's eyesight was restored in large measure, and he continued his researches into the nature of germ-cells. In 1892 he completed a set of *Essays on Heredity,* which were influential in the laboratory study of evolution.

Many Darwinians understood that this volume had "upset" the *Origin,* and hence they were much perturbed; many foes of Darwinism believed that it was now "overthrown" by the German professor of Freiburg. What a commentary that statement is on the pugnacity of human nature! We seem always prone to assume that somebody is fighting—fighting on our side or fighting against us. The fact was that Darwin had kept track of the early work of the young German and had seen in him an ally. Nor had Weismann any idea of a conflict. He admired Darwin and paid homage to him as to one who had been a great explorer of nature's unknown territory and had accurately described the boundaries of one region. Weismann simply penetrated farther into certain aspects of it by the use of his lenses. Even if Darwin had tried to investigate with the microscope, his one life was not long enough to do more than his part of the task.

In 1902 Weismann published two volumes, *The Evolution Theory,* summarizing the lectures given during his forty years of investigation. In the preface he explains his purpose: "In my introductory lecture in 1867 I championed the Theory of Descent, which was then the subject of lively controversy, but it was not till seven years later that I gave a short course with a view to aiding in the dissemination of Darwin's views. Then very gradually my studies led me to add to the Darwinian edifice and to attempt a further elaboration of it. . . . Not only are the vital units which we can perceive, such as individuals and cells, subject to selection, but those units that are too minute for our microscopes are subject to it likewise. . . . Many prejudiced utterances in regard to Natural Selection would never have been published if those responsible for them had had any idea of the inexhaustible wealth of phenomena which can only be interpreted in the light of this principle."

The truth was that Weismann had entirely corroborated Darwinism by his work in a new field and had given the quietus to Lamarckism. He proved—as Darwin never was able to prove—that acquired characters can not be inherited. He felt just as Darwin had felt about the effect of climate and food and exercise, and he knew that Darwin had marshaled much evidence against their effects on heredity. What was most needed was some evidence about mutilations. So he proceeded to the very rational experiment of mutilating mice for a great many successive generations; and showed that no amount of removing adult structures will remove anything from the heredity. He went very much farther. He showed that a series of generations is more than a chain of ancestry; it is a continuous stream of life that flows directly from germ to germ. To this current of heredity Weismann gave the name of "germ-plasm."

No one man, if he had had the use of the best eyes for fifty years, could have developed this theory by working alone. The germ-cells are so extremely small that the mechanism in them is at the limit of vision even with the aid of the best modern ultra-microscopes. Before a beginning could be made of the study of these cells a whole generation of observers had to struggle for a knowledge of what cells are. Not till the *Origin* had been published was it generally known that a cell has to arise from a previous cell, and not till 1873 was any picture drawn of the processes in the division of a germ-cell. In this long campaign for a knowledge of the cell young Weismann had been an eager volunteer, and during his ten years of blindness he followed its progress like a soldier in a hospital. When he was again able to use his eyes, his interest was centered on the "carriers of heredity," the stream of germ-cells.

He did not make any notable contribution to what he called "the raw material of observation, which will never bring us any further on"; he used his energies for seeing and interpreting the raw material that others had acquired by the minutest care in using the strongest eyes. He did not try to go beyond the inferences that must follow from what could actually be seen through his microscope. His reasonings were always lucid, with a canny appreciation of what facts must be; and they are often lighted up and humanized by touches of genial humor. The "germ-plasm theory" which resulted from twenty years of examining microscopical facts is briefly this: The material which determines every item of inheritance is not diffused through the whole germ-cell, but is contained in the nucleus of that cell. And even in the nucleus the real determining factors are limited to the chromosomes. Each chromosome, or in some cases each section of

one chromosome, represents a complete individual. It can not be any vague aggregate of similar materials, which *somehow* develop into a complex organism; it must contain within itself as much organized complexity as the adult body, for it produces precisely, by fixed operations, all the minute details of the body. Such a chromosome individual he called an "id," an abbreviation of *idioplasm,* an "identity mold." Since an id determines every detail of the organism that is to develop from it, it must contain a preparation for, or a specification of, every detail—such, for example, as the color pigment of the eyes or the length of the finger-nails. Weismann had no hope that we could ever see these counterparts of structure, but he argued that they must exist, for we can not conceive that the smallest of the inheritance items is caused by chance. Each of this infinite number of determining factors in an id he called a "determinant." If (he says in effect) there are in every growing embryo a great number of cells developing into structural forms, there may well be among them a sort of competition for nourishment; some of them may, in the fluctuations of the supplies or in their changes of position, be more fortunate than others, and so develop somewhat more vigorously than the specifications called for. In such a case there would be a variation in the animal that develops from that chromosome. This is no explanation of variation, and it is only a well-made guess; but it may be correct, and may carry us on one more step in our efforts to understand the ultimate nature of variation.

The last refinement of the germ-plasm theory has not been confirmed. And indeed the mental picture of ids and determinants has been shown to be considerably unlike what modern research has discerned with better apparatus. But Weismann's prime con-

ception—of a stream of hereditary germ-cells that are kept isolated from body cells—has been helpful in a high degree, as the latest and greatest investigator* of cells testifies several times: "The first fruitful attempt . . . was made on purely theoretical grounds by Weismann in one of those brilliant essays on heredity which contributed in so important a way to the enlargement of our views concerning cytological research. . . . The fulfilment of Weismann's prediction is one of the most interesting results of modern cytological research. . . . A vast and always growing body of data supports the general conclusions drawn by Weismann thirty-five years ago." H. E. Walter thus estimates what his work meant to science: "He led the biological children of Israel out through the wilderness upon a notable pilgrimage of fruitful controversy."

The pilgrimage has been in that Chromosome Land that is described in Chapter VIII. The controversies are outlined in the three following chapters.

*E. B. Wilson, *The Cell*, 1925, pages 500, 503, 576.

CHAPTER XXII

MENDELISM

While Darwin was preparing the *Origin* for the press, an Austrian monk, J. G. Mendel, was beginning a series of experiments on a phase of evolution with which Darwin had wrestled mightily—"hybridizing," the crossing of two varieties. Mendel had a mathematical mind and planned a statistical sort of experiment with bees and peas. The results of his work with peas have recently occupied a large part of the attention of many researchers in evolution. Though they were as simple and exact as A, B, C, they have been extended into a fearsome array of technicalities. The encyclopedias have long articles on Mendelism; books on genetics devote long chapters to the subject, illustrated with intricate designs to show the "heterozygous" possibilities; a whole field of advanced microscopy is based on Mendelism. Into such a whirlpool of terminology no reader of this book would care to be plunged, but he may care to see what the heart of the matter is; and I will try to show that in the following paragraphs.

Mendel worked for eight years with scientific zeal according to a perfectly simple plan, to secure a record of what happened when different kinds of peas were crossed. In order to make sure of clean-cut results he decided to observe only the most obvious characters and those that were in contrasting pairs—for example, tall vines and short vines, wrinkled peas

and smooth peas, green peas and yellow peas, hard pods and soft pods.

In the summer of 1857 he put the pollen of a tall plant on the pistils of some short plants and gathered the seed that resulted. Also he fertilized some tall plants with pollen from a short one. In each case there was a mixed inheritance, and of course the offspring of next summer would naturally be mixed. It sounds simple—like the experiment of a bright boy. It will sound different if we consider that there was no man in the world wise enough to predict the result. The greatest botanists of that time could not have told what percentage of Mendel's pea crop of 1858 was going to be short and what percentage tall. It is likely that every one of them—even including Darwin—would have guessed wrong.

Every plant was tall. At such a result Father Mendel must have been as pleased as he was astonished. Since the character of tallness appeared to dominate the character of shortness, he called it "dominant"; to the character that had receded out of sight he gave the name "recessive." He found that all the other pairs of characters behaved in the same way: smooth peas dominated the wrinkled kind; soft pod dominated the hard pod; yellow dominated green.

If he had been attending only to the characters of tallness and shortness, he might have supposed that his experiment was at an end; but he was not deceived by the uniform outside appearances. He wondered if any hidden mixtures lay dormant in this crop of tall plants, and therefore kept their seeds to plant in 1859. Then a new marvel appeared: out of 1,064 plants there were 787 tall ones and 277 short ones; the characters were nearly in the ratio of three to one. And all the other pairs of characters showed the same result: the

ratio of smooth to wrinkled was about three to one, and the ratio of yellow to green about three to one.

At this point, even if we confine ourselves to the one character of tallness, the complication begins. If the short vines of 1859 were fertilized from short vines, only short vines resulted in 1860; and the same was true for a third of the tall vines. But two-thirds of the tall vines yielded the same ratio as their parents —three tall to one short. You can see how a mathematician would revel in the fourth generation. His joy is cubed when he takes up the possibilities of crossing wrinkled peas with tall vines, and short vines with smooth peas, and short vines with hard pods—and all the rest of the possible combinations.

But Mendel was not carried away by the pleasures of combining seven characters taken two at a time. He was bent on deciding one simple and highly important question: Are these characters inherited independently of each other? His tabulations for the series of years proved that they were entirely independent—a tall vine might bear smooth peas, or vice versa; smooth peas might be in hard pods on tall vines, or smooth peas might be in soft pods on short vines.

In 1865 Mendel printed his report in a local scientific journal and gave an ingenious explanation, which showed real insight, of the three-to-one ratio. But scientists paid no attention to him. Even if his report had been widely read, it might not have meant anything; for there was no knowledge in the world by which to interpret his statistics. In 1900, however, when his article was rescued from oblivion and commented on by great biologists everywhere, the ratios were seen to have a deep importance. They indicated the mode in which the determiners worked in the chromosomes of the germ-plasm. The explanation—universally accepted now—is that the dominant and re-

cessive characters all depend on a mechanism that corresponds to Weismann's determinants; that they are essentially independent unit builders; and that they may persist, strong and complete, in the germ-plasm, though they may not build any character in the body, but may remain dormant for generations. Weismann's name for them is no longer used, because it represented an imaginary element of a chromosome; to-day the scholars say "factor" or "gene."

They picture the working of genes thus: When the blossom of a tall vine is fertilized from a tall vine, the resulting germ contains two genes whose work is to determine the height of the vine that sprouts from it; one comes from the father and the other from the mother; they are equivalent, and they produce a tall vine. Represent them by T T. The same condition holds in the case of a germ that is descended from two short vines; represent the genes by t t. Now if the blossom of a tall vine is fertilized by the pollen from a short vine, there is a pair of unlike genes, T t. One takes precedence; the T gene produces a tall vine. But the t gene is not destroyed; it is latent in the germ, recessive.

Suppose that next spring one of these T t flowers is fertilized from another T t flower. It appears that there is as much chance of distributing the genes one way as another. The result would be, if the law of chances held strictly, that in every four flowers one would have T T genes, one would have t t genes, and two would have T t genes. The first would produce a tall vine of pure breed, for there is no recessive gene of shortness in it; and the second would be a pure short vine. If these were kept apart and fertilized by their own flowers, they would forever breed pure tall vines and pure short vines. But the third and fourth vines, which are tall because of the dominant T gene,

carry the latent gene for shortness and will, when self-fertilized, produce short vines in every case where the T genes happen to be excluded. Three out of four, on the average, will have a T gene and will be tall; one of the four will have no T gene and will be short. The ratio of the tall and the short vines is three to one—the familiar three-to-one ratio in a generation of hybrid plants or animals.

Readers who wish to follow out the subject further from this simple beginning may consult the sixteen-page summary in L. L. Woodruff's *Foundations of Biology,* or may read the extended treatment in H. E. Walter's *Genetics.* These books are by no means impossible reading for a layman, and have good diagrams to illustrate many sorts of crossings.

During the last twenty years the laboratories have teemed with Mendelian experiments on many sorts of animals and plants, and all reports confirm the laws that were discovered in the peas of the garden of Mendel's abbey. It appears that all inheritance is a matter of building a new individual by the assembling of independent "unit characters," which are, in many cases, determined by the combination of two genes; if these are at odds with each other (called "allelomorphs"), one gene will dominate, and the individual will show that character in its body. But the recessive character has been perfectly preserved in the reproductive organs and may emerge in the next generation if there is the right crossing. The proof comes out prettily with the color-patterns of poultry or canaries, and with the fur of rats or mice. It has even been possible to get some observations on cattle and horses. Some of the freaks of inheritance in man no longer appear peculiar to a Mendelian, because he can see the operation of recessive characters. Here are two examples. (1) If a dark-haired father and a light-

haired mother have eight children all of whom are dark-haired, it is seen that the light hair is latent in the children and may reappear in the grandchildren, even if the children should all marry dark-haired persons. (2) Color-blindness can not be inherited directly from a color-blind father; all the children of a color-blind father and a normal mother will be normal; but half of the sons of the daughters will be color-blind. If a normal man marries a woman who carries the recessive genes of color-blindness, all the sons will be color-blind, and all the daughters, though normal themselves, will have color-blind sons.

Experimenters are now so familiar with these latent characters and with the laws of their appearing and disappearing that they know how to handle mixed races, to replace the recessive genes by dominant genes, and so to produce pure races. They understand why some kinds of fowls can never be pure. They can give useful advice to breeders. Through their microscopes they have seen the linking of chromosomes, have charted some of the sections of chromosomes that produce certain characters, and have gone far toward a preliminary acquaintance with the infinitesimal processes of building the mosaic of a new animal in a germ-cell. Few kinds of investigation give so much promise of further revelations.

To us who understand little of the details of Mendelism it might appear that all recent investigations have not resulted in any great advance toward new conceptions of evolution. For Mendelians tell us that "the essential thing" which they have demonstrated is that the determiners move along in the stream of heredity largely unmodified, that they may segregate themselves as independent units, and that they build an individual out of their separate unit characters; and Darwin declared more than half a century ago

that "An organism does not generate its kind as a whole, but each separate unit generates its kind." To us laymen these two statements sound similar. But scholars familiar with present researches see a vast difference between Darwin's vague prevision and Morgan's actual knowledge of heredity mechanism. An indication of what Mendelism means to-day is given in these sentences from a summary by William Bateson: "The breeder now knows what he is about and is able to interpret countless phenomena previously meaningless. . . . Enormous improvements can be made by applying accurate knowledge to the breeding of even such old-established crops as wheat, oats, tobacco, etc. If this is true of the crops which have for ages been the object of unremitting care, it will be understood that the cultivated plants of tropical regions offer limitless possibilities. The breeding of coconut, rubber, jute, cacao and many more has scarcely begun. . . . Genetic science shows primarily what can be expected, providing the breeder with an aim, and also indicates how it may be attained. . . . We may confidently foresee that the application of scientific method will in the case of the breeder's art effect a change in magnitude no less than that which has been witnessed in the other industries."

Bateson published his statement in 1922. In the same year an American woman, Maud Slye, published an article that reveals much more impressively the possibilities of Mendelism, *Biological Evidence for the Inheritability of Cancer in Man.** For fifteen years Miss Slye has bred mice in a laboratory of the

The Journal for Cancer Research, April, 1922. I do not know that this article is reliable; later investigators may show that Miss Slye's observation was faulty. But her method of work, showing the reliance that all physiologists place in Mendelism, furnishes an excellent illustration of possibilities.

University of Chicago, trying to determine the nature of the inheritance of the different kinds of cancer. Without a knowledge of Mendelism her work would have been impossible; with this knowledge she has been able to explain what no records of human ancestry could ever have revealed. I will give a brief summary of her findings after explaining the nature of cancer.

Cancer appears to be an inability of cells to stop forming when they normally should. If, for example, a person breaks the skin on his lip, the cells at that place begin multiplying to replace the injured tissue; when their work is completed, they would normally stop growing; but if they lack the mechanism that controls growth, they will continue to multiply and will form abnormal tissue that ramifies through the flesh. This tissue is cancer.

Miss Slye finds that the absence of a mechanism for growth-control is inherited *as a recessive.* One of her many experiments will illustrate what this means. She mated a female that had cancer of the breast and lungs to a male that was known to have no cancer in his ancestry. In the first generation there was no cancer, since all the offspring had the dominant gene of non-cancer. But the recessive gene of cancer was in their germ-plasm and appeared in their descendants exactly according to the Mendelian formula. There were three lines of descendants: mice that never developed any cancer through fifteen generations; mice that were all cancerous; mice of mixed inheritance—some cancerous and some not. Other breeding experiments show strikingly how the Mendelian laws explain what would otherwise be baffling mysteries in the inheritance of cancer. "By the continued selective breeding of a heterozygous individual with a non-cancerous mate all occurrence

of cancer was held off until the thirteenth generation." "When a given type or location of cancer is bred in, it can be manipulated with absolute accuracy by the type of selective breeding used. It can be made to hold off for any number of generations desired or to appear in the next generation."

It is hard to refrain from exclaiming about the possibilities for human welfare that may be revealed in further researches by the aid of Mendelism. This knowledge of heredity may be opening the way to a control of the most dreaded of diseases. Its future benefits to the race are beyond guessing.

CHAPTER XXIII

DE VRIES'S MUTATIONS

In the late eighties Professor de Vries, a Dutchman at the University of Würzburg, began an intensive study of the sports of an evening primrose. In the course of a few years he saw this well-spring of variation spout out a number of new species and an endless series of varieties and sub-varieties. To the new species that thus appeared he gave the name "mutations." Beginning in 1900, he published a series of essays on his observations, which he collected under the title *Mutationstheorie.* In 1904 he lectured on the subject in America and prepared a large volume to expound his views of evolution, *Species and Varieties: Their Origin by Mutation.* The gist of his theory is that the smaller variations occur within narrow limits, that they fluctúate back and forth without progressing and do not develop into new species, but that species originate at a sudden bound as sports—as "mutations."

This view had a great vogue. Though it was based largely on the observations of the one plant, and though it contained nothing essentially novel, many experienced botanists subscribed to it and paid homage to it. It was commonly spoken of as a sweeping revision of the Evolution Theory.

Shrewder minds seem never to have been much impressed by it. Bateson thought that de Vries's species were only kaleidoscopic combinations of unit char-

acters. Within a few years it had been severely criticized by experimenters whose results were published in the Carnegie evolution series. S. J. Holmes said: "De Vries's mutationstheorie gained acceptance, especially in America, with a rapidity which was quite unjustified. It was regarded with extreme suspicion by most students of taxonomy and distribution."

The suspicion was based on these facts: (1) that de Vries had hunted high and low before he could find such a mutating plant; (2) that his primrose was a recent arrival from America (probably about 1875) and was therefore in an artificial "sporting" condition; (3) that it had been a cultivated plant in America; (4) that de Vries could not draw any line between lesser mutations and greater fluctuations; (5) that his primrose gave every sign of being a hybrid, which was revealing latent recessives; (6) that American cultivators of the plant saw some of his so-called "new species" spring into existence, and that these mutations therefore seemed like mere "periodic" or "ever-sporting" varieties—the very sort of variation against which de Vries had cautioned amateur observers.

The most curious shortcoming of the mutation theory is that it differs from Darwin's only in degree.* Darwin repeatedly says that sports occur in nature and are probably one source of evolution. In several passages de Vries credits Darwin with understanding these two elements, and he does not set up a denial of the correctness of Darwin's analysis. He puts the case clearly on page 573 of *Species and Varieties*: "There are two possibilities, and both have been propounded by Darwin. One is the accumulation

*In his earlier essays de Vries apparently meant that his mutations would supplant Darwin's variations; but in 1904 he declares distinctly and repeatedly that small variations *do* accumulate in accordance with Darwin's theory; and he says that Darwin *did* recognize the sudden "saltations" or mutations.

of the slight deviations of fluctuating variability; the other consists of successive sports or leaps taking place in the same direction." He says that his mutations "comply with the demands made by Darwin as to the form of variability which is to be accepted as the cause of evolution." De Vries's modest proposal to change the emphasis of Darwinism is in striking contrast with the extravagant opinions of some of his disciples; and even that proposal seems to be evaporating under recent examination.

It will be appropriate to close this account of mutations by quoting what de Vries says of Darwin: "In honor of him who with unsurpassed genius and by unlimited labor has made his law the basis of modern thought."

CHAPTER XXIV

How Evolution Stands To-day

I. The Microscope vs. the Field

The men who study evolution to-day work in many divisions at highly specialized labors. They are divided into two principal groups: those who study cells in a laboratory, those who dig fossils and collect specimens in the field. From their earliest years of academic training till they are gray in the service they live opposite kinds of lives and see nature from opposite sides. Naturally, therefore, if we hear of their disputes, their views seem to us conflicting, and we wonder whether Darwinism is being torn to pieces in an arena.

It is this situation that Bateson was describing when he made an address at Toronto in December, 1921. He could not have chosen a more pertinent topic. He handled it wisely and with good effect for an audience that understood him, calling their attention to the rift in their ranks, to the need of getting together and sympathizing with one another. In strong terms he spoke of how, if the estrangement continued, the men in the field "will feel the ground fall from beneath their feet, while we who look up from our work-tables may find our eyes dazzled and blinded." The conclusion of his speech was this: "Let us, then, proclaim in precise and unmistakable language that our faith in evolution is unshaken. Our

doubts are not as to the reality or truth of evolution, but as to the origin of species—a technical, almost a domestic, problem."

Bateson's address was widely celebrated in the newspapers. Of course a mere report of what he said would not have been entertaining news; so the papers filled their space with what I can only term a "celebration" of the address. Who wants to read the "precise and unmistakable language" in which a convention of scientists asserts its faith in the reality of evolution? Newspapers know that their readers will be much better off if they are told that "the theory of Darwin still remains unproved." That typical case of the misunderstanding of the differences of opinion among scientists is a fine illustration of how evolution stands to-day: it stands unshaken in scientific opinion, but it is all shot to pieces in the opinion of the newspapers.

Every intelligent editor ought to resolve to keep his sporting reporters away from scientific gatherings, so that the meetings shall not be described in terms of an athletic contest. He ought to feel that scientific faith is of more importance than the domestic problems of science. Because the press has so systematically misled the public in its descriptions of the differences between the Batesons and the great body of zoologists, the Council of the American Association for the Advancement of Science adopted the following resolution a few months after the garbling of the Toronto address: "No scientific generalization is more strongly supported by thoroughly tested evidences than is that of organic evolution." That is where evolution stands to-day.

Only one further comment is needed on the differences between the men of the microscope and the men of the field. Researchers who specialize for years

on the eggs of grasshoppers or the Arctic ice-sheets lose all the perspective that we laymen have. All specialists are concerned with *differences* in the phases of evolution; when they write their articles and speeches they must emphasize the special differences between the departments of knowledge. Hence to the outsider they seem to be calling each other ignorant and to be tearing evolution to pieces. This view of ours is quite unlike what is in the scientist's mind. All that we know about evolution he takes for granted; it is to him like an A, B, C. He assumes that the record in the rocks is a truism. "The lines of argument converging to support the theory," says Bateson, "are so forcible and so many that no alternative can be entertained. The geologic record is conclusive." Even Jacques Loeb, a biologist who made "sardonic war on the Darwinists," did so, we are told by an admirer, "not because he disbelieved evolution; on the contrary, he held it to be a self-evident fact." As to the general truth of evolution, there are no differences between the workers at the tables and the workers in the rocks. They may be sardonic about details of *how* variation operates. They are at one as to the unmistakable fact that it operates. They are in complete agreement with the statement that if evolution were given up they could see no opportunity to seek for further knowledge of nature.

II. Orthogenesis and neo-Lamarckism

The skeptics described in this section are at the opposite pole of mental operations—they are metaphysicians. Though their speculations are diminishing and growing very thin, their mode of thought is still an element in discussion of natural selection and must have a place in an account of how evolution

stands to-day. It is an alluring mode of thought. It takes us out of the confinement of fixed laws of nature and shows us a prettier region. It was irresistible to John Burroughs. It makes a strong appeal to all of us who feel the attractions of poetry and philosophy.

The name for this pleasing conception of evolution is "orthogenesis." The best way to understand it is to approach it by way of the mind of primitive man. He necessarily assumes that all the forces of nature are persons. He can not possibly do otherwise. Before he dares to cut down a tree, he must make a prayer to the spirit of the tree; he makes excuses to the soul of the bear that he has killed; he tries to coax the personality of the rain or to appease the demon who makes a drought. This way of peopling every part of nature is inevitable, for the savage can not conceive why anything but personalities should bring him blessings or cause destruction of his hopes. The whole progress of civilization has been a very slow realizing, in one stage after another, that a stone falls because of natural law, and that no one has ever encountered the spirit of a tree. All advance of human knowledge has been farther and farther into the region where impersonal laws work, and where no other cause of actions can be discovered by the senses.

Every step in such advance has caused bewilderment and fear. To deny that there is a spirit in the corn is a sacrilege against a deep faith. It takes away the natural and understandable human explanation, and it substitutes an impersonal law that is opposed to all our mental workings. Yet the demonstrations have been made, one after another. Educated people in 1750 could not accept a mere cause-and-effect explanation of a comet. "How," they asked with indignation, "could the operation of mechanical

laws, acting by blind chance, bring such a portent at such a crisis in human affairs? No, there is some deeper and more spiritual power manifested in a comet." That is the appeal to which our minds are always sensitive—the horror of "blind chance" and the insistence on "a deeper power." Yet by 1850 most educated people had abandoned the petty idea of a special force in comets, and had accepted the prosaic explanation of a mass of matter impelled by fixed, invariable laws.

Every proposal to remove the spirit from any part of nature has always seemed to most of the people of that time to be a proposal to remove all spiritual matters from our thoughts. But the progress of science has never meant that. The advance of the realm of fixed laws has only meant the removal of the individual, local, petty, supernatural forces. We can not today reach a primary cause of all natural laws except by supposing some mentality or spiritual force that ordained them. Science has kept discovering, one step after another, that the controlling spirit is farther from our direct senses than had been supposed; and it is still enlarging our conception of the great extent of natural law. Yet it never expects to prove that there is nothing but mechanism in the universe. It is always increasing our awe at what must lie beyond science.

All this is familiar enough and needs no explaining here. I simply wish to be sure that it is recalled to the reader's mind before he goes on.

Many scientists—perhaps most of the best ones—ponder upon the forces that are beyond our senses. Every thinking mind must always be wondering, "What is it all about? How does it all come to pass?" As soon as scientists come to the limit of mere material investigation they, like the rest of us, are at liberty to speculate on the how.

Now there is a point in the study of variation where the senses fail us. When the most rigorous and materialistic scientist has seen the regional bands of chromosomes, he can see no farther; no eye has beheld the beginning of variation. The student of fossils comes to a point at which he can learn nothing more of the origins of those different species that developed and flourished and died. What made them vary in such an orderly way? There they are, displayed to our wonderment, in a series that progresses, as it were, in a straight line of development. How was the line determined? Surely, says reason, it could not have come by blind chance. May it not have been that in the make-up of each organism at any one period there was some sort of guiding impulse, something innate that directed the species on this straight line? That is logical. To this kind of reasoning has been given a name which means in Greek "development in a straight line"—*orthogenesis.*

I will give below a series of numbered paragraphs that will show, nearly in chronological order, the different forms which this logic of straight-line development has taken in the thought of leading minds during the last hundred and twenty years.

1. Lamarck outlined his theory of evolution in four laws, the first of which says, "Life, *by its proper forces,* tends"—etc. That means that life has within itself some sort of force which is—like free will, for example—independent of mechanistic regularity. The second of Lamarck's laws states that "A new organ results from a new want continuing to make itself felt." Lamarck did not mean that the conscious desire of an animal originated variations, but that an entirely unconscious impulse, a "want" of some organ, caused it to "move" in such a way that vital "fluid" was brought to that part and caused it to develop.

2. This "want" of an organ had such resemblance to a striving or purpose or will that it was regularly interpreted by thoughtful English scientists as a sort of "volition" within the organs, and their interpretation was natural and proper a century ago. How could they, in those early days of science, accept a mechanistic explanation? Their philosophy was deep ingrained in the mind of Darwin, so that he had to encounter it early in his reasonings toward a theory. He says, "It became evident that neither the action of the surrounding conditions *nor the will of the organisms* (especially in the case of plants) could account for the innumerable cases of adaptation."

3. Lamarck's fundamental notion was often expressed (in an ancient phrase) as "an internal power" or "a principle of improvement," and this form of it was held strongly by such superior minds as Lyell and Hooker. It was a chief cause of their reluctance to accept such a purely mechanical explanation as Darwin's natural selection. In one of the earliest letters that Darwin wrote to Lyell about the *Origin* he shows that Lyell has raised the old Lamarckian objection to "blind chance," for he writes: "The improvement of our cattle, pigeons, etc., does not presuppose or require any aboriginal 'power of adaptation' or 'principle of improvement'; it requires only diversified variability." There was the issue, clearly raised, that vexed the scholarly world. All could see the great weakness in Lamarckian ideas which Darwin saw—it does not apply to plants; and some could concede that it is not a necessity of reasoning; but many nevertheless felt that it was a true philosophy of the causes of evolution.

4. An eminent, able and influential American was Professor E. D. Cope, of the University of Pennsylvania, who could not reconcile himself to Darwin's

natural selection, because, as he wittily put it, "Survival of the fittest does not explain arrival of the fittest." In 1887 he made a strong attack upon natural selection, arguing that there was a definite internal force which directed the evolution of a species by causing modifications, and that those acquired modifications could be inherited. He had thus frankly returned to Lamarckism, because he could not accept an explanation that depended on fixed mechanical laws.

5. Cope's Lamarckism is the latest survival of note that I can learn of. Since his day the "principle of improvement" has shrunk and has grown so different from Cope's ancient vigor that it is almost ghost-like. It has become "neo-Lamarckism." It merely argues that "perhaps" acquired characters, "in some unknown way," *may* be inherited. And even on this possibility it lays very little stress. Its nourishment is in the conviction that natural selection is not a sufficient explanation, that there must be some kind of unknown power which directs the lines of development. H. H. Newman says in his *Readings in Evolution* that "paleontologists almost universally lay hold of both Lamarckian and orthogenesis ideas." A good example of them is Professor H. F. Osborn. He is a stalwart figure, a thorough scholar, who has gone almost as far as any modern in the mechanistic conception of how life developed from inorganic substances. He admits that "the prevailing opinion among most modern experimental zoologists is against orthogenesis," and he is the stoutest champion of Darwinian evolution. Yet even this man says emphatically: "The gradual evolution of adaptive form is directly contrary to Darwin's theoretic principle of the selection of chance variations." His word "adaptive" means, as he himself has explained, orthogenetic.

6. In Lull's *Organic Evolution* (1921) there is a chapter on orthogenesis which states the issue with such perfect fairness and acuteness that we can not tell surely which way the author's sympathies lean. He says that orthogenesis (as distinguished from ortho-selection) is an unproved theory, but that it may be proper to believe in a force which "determines" the direction of the variations.

To most biologists it would seem that the results of evolution must usually appear as "straight lines" of development. Surely the little ancestor of all the horses varied toward shorter legs and longer legs, toward bigger side-toes and smaller side-toes; but the shorter legs and bigger toes were unfavorable in the struggle for existence, and so perished, leaving no record of themselves. All the successive variations toward larger legs and smaller toes were useful, were reproduced, and so were recorded in the rocks. The resulting evolution was in these "straight lines," to be sure; but the lines were merely the successful remnants of variations in many directions. Natural selection destroyed all other lines. There never was an inward tendency to one line, but only an outside force which extinguished every line except that one—and it is this which the paleontologist sees. The egg-layers of the crickets on Long Island (see page 136) have no "tendency" or "vital principle" that directs them to develop in a straight line toward more or toward less length; they vary both ways in any group of crickets. What happens is, broadly speaking, that the conditions of temperature and soil on Long Island kill every cricket in a given locality if its egg-layer is less than so many millimeters long. If a certain European nuthatch had a bill less than such a length in a certain locality, it starved; hence all the bills, as the species ranged northward, were developed in

a straight line of change. But no "principle of development" need be conjured up to account for the change; the nature of the cones that contained the birds' food determined the course of development. So always.

Orthogenesis does not explain anything. It is merely the last slight remnant of the primitive desire to imagine an explanation that is not mechanical.

III. The Nature of Variations

Since 1900 there has been a great deal of skepticism about the nature of variations. The Mendelians have challenged every old, easy-going opinion and have asked, "What proof is there that any new character ever appears? What proof is there that variations can be accumulated as Darwin supposed?" I will summarize the three principal reasons for such doubting.

1. *The mere rearrangement of genes.* If a pouter pigeon and a carrier are bred, the hybrid offspring are not simply a combination of pouter and carrier; and if the hybrids are mated, their offspring are still less like the thoroughbred grandparents. It is found that after a few generations of such mixed mating the form may "revert" to the ancient ancestral type of all the artificial breeds of pigeons, and this fact suggests that, in spite of "breeding true" for many generations, no new type has really been created, but that careful breeding has simply collected or suppressed certain factors—that is, the genes.

A similar conclusion is reached in the case of any other domestic breed of plants or animals that is hybridized. There seems to be a possibility of explaining the variations as mere rearranging of the genes that were present in the parent stock. It is hard to get

evidence of any new character that originates as a new gene. To some observers no change seems fundamental; every change, they think, could be explained as a mere rearrangement of elements that have always been present. All the propagation of new varieties of wheat may be explained as a mere reassortment of the same old genes. A field of wheat is a mixed population of different strains; if a Patrick Shirreff walks through it and detects one stalk that looks peculiar, and if he selects it and breeds it, what proof has he that anything new has been created by chromosomes? May not the new variety be merely a bringing to the surface, or a new assortment, of the same old ancestral units that have always been in wheat?

2. *Pure lines.* One noted investigator, Johannsen, bred several generations of beans in such a way that he removed all traces of hybridizing and secured a "pure line." The beans propagated from this line for many generations remained true to form; no new character appeared; no old ones disappeared. There was no hereditary variation in the pure line. Other experimenters secured similar results. Pure lines of animalcules showed no variations through many generations, but seemed to have a set of characters "as rigid as iron." There were published reports to the same effect about potatoes and barley and hens and garlic. Bateson announced that "Supposed variation is commonly nothing but the recurrence of a recessive form; more often the direct product of a cross."

3. *Fluctuations.* When any "mixed" population is investigated, doubts of variation arise. Statistics show that seventy-two-inch men have sons who average much less than that height, and that sixty-six-inch men have sons who average much over that height. The human population fluctuates about a mean height of sixty-eight inches. A pailful of a certain kind of

scallops collected at random shows great variation in the number of "ribs" on their shells: a few have only fifteen ribs and a few have nineteen, but the majority have seventeen; the number of ribs fluctuates about seventeen as a mean. A pailful of potatoes from several hills shows great differences in size, but there is a mean; the small ones will produce some large offspring, and the large ones will produce some small descendants. De Vries wrote long chapters to contrast this sort of "fluctuating variability" with inheritable mutations. He showed that "long-continued selection of fluctuations has absolutely no appreciable effect, that centuries and perhaps geologic periods of continued effort in the same direction are not capable of adding anything to the initial effect." J. A. Thomson said that "fluctuations are inadequate ever to make a single step along the great lines of evolution," and numerous writers have echoed the idea.

But numerous writers have also defined "fluctuation" in a quite different way, pointing out the simple underlying truth of all variability—to wit: So far as fluctuations are bodily due to environment, they are not material for evolution; but so far as they are germinal (as some part of them may be) they are inheritable and are material for evolution.

The skepticism arising from these three sources has been fruitful, for it has challenged careless assumptions and has made all reasoners about evolution take heed. It has also had an unfortunate effect, for it has made general readers suspect that there is no longer any such thing as the inheritable variations on which Darwin built a theory. The public heard that Professor Jennings had "overthrown Darwin" by showing that in a pure line of animalcules there was no inheritable variation; but the public did not learn about the rest of his work. He did not take it

for granted that he had disproved natural selection by one series of experiments. He tried again with a different species, and here he found that in pure lines there *was* variation which could be accumulated by selecting through many generations. Few students of heredity would now deny that there may be variations in pure lines and that these changes may be inherited. But these changes must be "mutations" and not modifications—terms defined in the next paragraph.

The scholars of to-day seem fairly well agreed, after two decades of the most thorough searching of evidence, that there is now "a new content in the problem of selection" and that "the appreciation of its limitations has but accentuated its possibilities."* They have winnowed the classes of variation and discarded the chaff of non-essential external appearances; the resulting scheme is in three groups:

1. Modifications—changes in the body, acquired characters.

2. Combinations—reassortment of genes, not originating any characters, but giving new combinations of old ones. These may be inherited.

3. Mutations—appearances of characters that have not existed in ancestors, characters that are due to actual fundamental changes in genes.

(A fourth group should be added for scholarly completeness—the "fluctuations" described above. These may be either modifications or combinations.)

No modification can be inherited, since it is not a change in the germ-cell. A combination or a mutation may be inherited, may be selected, and may be material for new adaptations.

The simplicity of the scheme of variations may

*L. L. Woodruff's *Foundations of Biology*. Pages 299-306 give a concise account of the kinds of variation; this has clarified my mind and has been effective in college classes.

look suspicious to any one who has wrestled with the many confusing terms that have been current in the literature of evolution, but it is a really valid scheme. It does not attempt to classify all the different kinds of variation by their outward appearance, for nothing about heredity can be known from the appearance. It takes account only of the fundamental distinctions. First it sets aside all body changes (modifications) as having no part in evolution; then it recognizes the two different kinds of inheritable changes.

The terms "modification," "variation," "fluctuating variation," and "mutation" have been used with such different meanings that an unwary reader may suppose, in passing from book to book, that authors are at odds with one another when they are in agreement. I shall attempt a brief explanation of the chief meanings that have been common.

"Modification" was used by Darwin and Wallace to mean any sort of change in offspring which could be transmitted to descendants; it was synonymous with inheritable variation. Now it is restricted to changes in the body that can not be inherited.

"Variation" is, as it always has been, the generic name for any sort of way in which offspring differ from parents without any regard to whether the difference is in the body or in the germ-cell. It should be realized that Darwin could not make the modern sharp distinction between bodily and germ-cell variation; he could only speculate on the probability that some variations were not inherited.

"Fluctuating variation" or "fluctuation" often means in recent books a change back and forth about a mean, a change that does not cumulate to form permanent alterations; but it is also used to include small changes of both kinds—modifications and inheritable combinations.

"Mutation" was invented by de Vries. Originally he used it to describe an extreme variation that can be inherited, a notable sport, so different from parents that it deserves the rank of a new species or distinct variety, like the ancon sheep. A common synonym at one period was "saltation"—that is, a sudden leap to a new variety. When de Vries found that he could not distinguish the degrees of mutation, but that very slight variations might be as fixed and distinct as the largest sports, he altered the meaning to include any change of the germ-plasm that is regularly transmitted. This is now the accepted meaning, but the original one still lingers in some books.

Further knowledge of variation seems most likely to come from such work with the microscope as that in which E. B. Wilson and T. H. Morgan are now the leaders. They are looking directly at chromosomes, are learning more about them every year, are teaching a host of experimenters how to observe them; and there is the citadel of the mystery of variation.

In this paragraph I place three judgments on the nature of variation. P. C. Mitchell, 1900: "Although knowledge of variation has become much wider and more definite, the estimate in which natural selection is held has changed very little since Darwin and Wallace first expounded their theories. The advance of knowledge has supplied no alternative to the Darwinian principles." C. C. Nutting, in an address before the Genetics Branch of the American Association for the Advancement of Science, December, 1920: "In conclusion it seems to me that we are justified in maintaining that Mendelism and the mutation theory have neither weakened nor supplanted the Darwinian conception of the origin of species by means of natural selection." S. J. Holmes, who wrote

for the *University of California Chronicle* of July, 1921, an admirable summary of recent opinion, lucid and penetrating: "The status of natural selection has become more firmly established than it was in the time of Darwin. The studies of Weldon, de Cesnola, Bumpus, Davenport, Tower, and Morgan have shown the actual operation of selective elimination. . . . The reproach of Lord Salisbury that 'No man has ever seen it at work' has now been definitely shown to be without foundation. . . . The discoveries in the few years that have elapsed since the publication of Bateson's address [of 1914] have afforded positive evidence of its unsoundness. The discovery of multiple allelomorphs has lent strong support to the view that Mendelian characters are due to factor *transformations* instead of merely gains or losses. Recent work has added further and critically tested evidence of the origin *de novo* of dominant characteristics. It has shown that recessive genes occasionally mutate to form dominant factors. . . . The mutation theory has been brought more nearly in accord with the conception of the origin of species by the gradual method, as outlined by Darwin."

Even more significant than such testimonies are the two following quotations from men who are more familiar with the detailed study that has led to skepticism about natural selection. L. L. Woodruff, who has minutely studied heredity in animalcules, summarized his opinion thus in 1923: "Selection is not shorn of its importance either practical or theoretical. . . . Natural selection may afford an explanation of the adaptations of organisms to their environing conditions." E. B. Wilson, whose work on cells is the standard authority quoted in reference books, gave this judgment in 1914: "To such minds [he was including his own mind] it will seem that the principle

of natural selection, while it may not provide a master key to all the riddles of evolution, still looms up as one of the great contributions of modern science to our understanding of nature."

IV. The Faith in Natural Selection

"All the world now travels along the course Darwin established."
—John Burroughs.

According to the newspapers Darwin is always being "overthrown." Indeed he has been bowled over so many times that I have wondered who sets him up again. The latest overthrower, strangely enough, is John Burroughs, who says in an *Atlantic* article of August, 1920: "Darwin has been shorn of his Selection doctrines as completely as Samson was shorn of his locks."

But who sheared him? Where is this Delilah concealed? I can find the Philistines who would like to bind Darwin, but nowhere can I come upon any trace of his shorn locks or of the clever scientist who cut them off.

Burroughs does not tell who betrayed Darwin. He names Weismann in one place, and this rouses our suspicion; but Weismann was a most downright and outspoken champion of Natural Selection. Instead of overthrowing anything Darwinian he says, "My studies led me to add to the Darwinian edifice." The two volumes of his latest and greatest work testify unqualifiedly that Darwinism "stands on a secure basis of fact." Especially does Weismann insist on the prime importance of Natural Selection and of "the wealth of phenomena that can only be interpreted in the light of this principle." He rests his own method and the hope of fame on it: "This extension of the principle of Selection to all grades of vital units will endure even if everything else in the book should prove transient. . . . The slow and gradual effects

of Natural Selection can not be explained, so far as we know, in any other way."

Burroughs hints that de Vries may have been the wily one who lulled Darwin to sleep, but de Vries is not guilty. He recorded his loyalty to Natural Selection unmistakably in 1903: "My work claims to be in full accord with the principles laid down by Darwin. . . . The great principle enunciated by Darwin reigns supreme."

Burroughs quotes against Darwin a man who is president of the American Museum and a noted Columbia professor, H. F. Osborn. But there does not live any more staunch warrior against the Philistines than this same Osborn, who declares in his *Origin and Evolution of Life*: "That Natural Selection is continually operating at every stage of the transformation there can be no doubt." He testifies that "pure Darwinism has been refined and extended and powerfully advocated by Weismann and de Vries," and he pays homage to "the master mind of Darwin."

It might seem possible that Professor T. H. Morgan, the greatest of the chromosome explorers, was the wielder of the shears; for Burroughs quotes his remark that "the spirit of Darwinism, not its formulæ, is our best heritage." This is so brought into the article as to make it sound suspicious, as if it might mean, "Darwin didn't know much, but he was a fine fellow." What Morgan really thinks about Darwin as a scientist he has expressed thus: "Darwin's theory of Natural Selection still holds first place to-day in every discussion of evolution. . . . I heartily agree with my fellow biologists in ascribing to Darwin the first place in biological philosophy. . . . Stated in these general terms [that is, as I have stated it in Chapter IX] there is nothing in the theory of Natural Selection to which any one is likely to take exception."

Baffled and disappointed by every name that Burroughs mentions, we might next guess that Darwin had been delivered up to his enemies by some religious argument. But Burroughs emphatically states that he does not want religion in nature; he can not believe in a "creator who controls"; he rejects the idea that "the stream of variation is guided by a higher power," and he declares that "we see nothing like purpose or will in nature's scheme of things." He says that we "float in a boundless sea of energy; and that is all we know about it." For my part, I had rather be tied up at the old dock of Natural Selection than adrift on such an ocean as that.

Amadeus W. Grabau is certainly one of the foremost of modern geologists, and he is not in any way radical or peculiar or given to over-statement. In his scholarly two-volume *Textbook of Geology* (1921) he has a chapter on fossils, an exposition of the commonplace facts, which closes with a sentence that is clearly intended to state a commonplace and undisputed truth: "The principle of Natural Selection has come to be of fundamental significance in all biological studies, and its discovery and announcement mark the beginning of a new epoch in the intellectual development of the human race."

Edwin S. Goodrich, Linacre Professor at Oxford, says in his chapter on Natural Selection, 1924: "The Darwinian theory still stands unassailable as the one and only rational and scientific explanation of evolution by natural forces."

I have searched high and low for the reputable scientist who has cut off Natural Selection, and I can not find him. Bateson, to be sure, has snipped at it, saying in one of his articles that "the modern geneticist assigns to Natural Selection a subordinate and inconsiderable rôle." But his opinion, when con-

trasted with all the representative quotations given in this chapter, is scarcely Samsonian. Perhaps the vigor and wit of Cope's onslaught a generation ago seemed to Burroughs like a complete destruction; for Cope was only three years younger, was much applauded by his generation, and doubtless had a strong influence upon the middle-aged Burroughs.

Burroughs himself rejoices in the enduring vitality of Natural Selection. In this very article he formally confesses his faith and hymns his praise: "I believe in the accumulation of variations. . . . Species have come to be what they are through Natural Selection. . . . Adaptability comes through this fight for life. . . . Natural Selection gives speed, strength, keenness; it works upon these attributes and tends to perfect them." And he concludes with tributes like this: "Darwin is still the most impressive figure in modern biological science. . . . His candor and devotion to truth are a precious heritage to all mankind. He taught us how to cross-question the very gods of life in their council-chambers. . . . All the world now travels along the course he established."

V_3 *Darwin Did Not Rely on the Inheritance of Acquired Characters*

The subject of this section is, in one way, so technical a question that any reader should skip to the next chapter if the title rouses no emotion in him.

The seemingly petty matter has assumed a curious importance in popular arguments about evolution. Since it is frequently stated* that Darwin "appealed

*For example, in Herbert's *First Principles of Evolution:* "Darwin fully acknowledged the effects of the environmental factors, and relied upon them in many cases." Herbert uses "effect of the environment"—as Darwin and Wallace did—to mean inheritance of acquired characters.

to" the inheritance of acquired characters or "fully endorsed it" or "emphasized it," and since such inheritance is now a discredited theory, many general readers have gathered a vague idea that Natural Selection was built on a foundation that crumbled.

The idea might seem, at first sight, to be warranted by Weismann's way of putting the case in Volume I of *The Evolution Theory*: "'Darwin believed the Lamarckian factor to be indispensable. . . . It seemed to him to offer the only possible explanation of the disappearance of characters. . . . He even directed his own particular theory of heredity to the explanation of this supposed form of heredity." Those detached sentences may sound as if Darwin had "relied on the Lamarckian factor." But in fact they mean nothing of the sort. Weismann's pages, when read entire, bring out a different topic—to wit: "Lamarck never so much as put to himself the question whether acquired characters can be inherited; he assumed it as matter of course. But Darwin accepted it, hesitatingly and cautiously, because there was no other way of explaining the disappearance of organs which have degenerated." Weismann was championing Darwin's skepticism and seeking for proof that acquired characters can not be inherited.

Another accusation brought against Darwin's theory is that he would have nothing to do with Lamarckism when he wrote *The Origin of Species*, but that later in life he changed his views and accepted the inheritance of acquired characters. This idea is used by L. T. More in *The Dogma of Evolution*. He says: "It is well known that Darwin changed from his early and passionate advocacy of natural selection as the sole and sufficient cause of evolution to the milder view that it was an important factor. . . . Only after facts had multiplied, showing the inade-

quacy of natural selection, did biologists begin timidly to take Lamarck's doctrine seriously. "If one can read the signs aright, we may expect to have an increasing attempt to explain the cause of evolution by the inheritance of acquired traits." Professor More hopes for a revival of Lamarckism. The starting-point of his hope is that Darwin changed his mind after writing the *Origin*. Of course Professor More's idea and the idea that Darwin relied on Lamarckism are contradictory and ought to cancel each other; but, strangely enough, they combine to produce a suspicion that somehow or other Darwin put too much faith in Lamarckism at some time or other, and thus vitiated his book. Hence it becomes necessary to explain that Darwin's views of the effect of the environment were perfectly consistent throughout the last thirty years of his life.

Darwin was always doubtful whether any changes produced by the environment could be inherited. He could not deny flatly such a possibility, because the evidence in favor of it was unanswerable. (For that matter, the very latest writers on heredity do not dare to deny flatly.) Every one of the men whose judgment he most respected believed in the inheritance of characters that were produced by the environment. To stand out against such pressure would have been foolhardy. To deny the inheritance of acquired characters in 1859 would have been to defy the universal conviction of the learned world. No voice was raised against such a belief until 1875, and no voice of authority until 1881. Darwin had to accept it, but he did so grudgingly.

Such grudging acceptance is not "basing a theory upon." Nor did Darwin ever vary from his original position, which he thus described in a letter to Wallace, written in 1857: "I suppose some very little

effect must be attributed to such influences [of environment], but I fully believe that they are very slight."

The only reason I can discover for asserting that Darwin's views altered after 1859 is a passage written thirty years ago by Professor H. F. Osborn in *From the Greeks to Darwin,* page 240. Osborn declared that there was "a slow change of mind towards the Lamarckian factor" and quoted as evidence six lines from a letter of 1862 and four lines from a letter of 1876. The supposed evidence in the first letter is this statement: "My present work is leading me to believe rather more in the direct action of physical conditions." But the whole emphasis of Darwin's correspondence at this period is indicated by a phrase in the sentence that follows this one, in which he says that the matter is "so confoundedly doubtful." Less than four months afterward he wrote to Lyell: "The more I work the more satisfied I become with variation and natural selection." The second letter from which Osborn quotes is one that thanks Moritz Wagner for a copy of his essays, in the course of which Darwin says, "The greatest error which I have committed has been not allowing sufficient weight to the direct action of the environment. . . . Your case of *Saturnia* is one of the most remarkable of which I have ever heard." This was Darwin's way of being extremely polite toward a German, who was bombarding him with Lamarckian evidence, at a time when his views were "meeting a good deal of opposition in Germany" and when the Germans were "very contemptuous." Darwin showed the same kind of gentle, and rather excessive, deference to Wiesner and Neumayr. There are two other letters in which he expressed the idea that he has perhaps not given sufficient weight to the action of the environment. But

I can not find in the *Life and Letters* any other reference to a change of opinion after 1872, nor even an indication that he was any more worried than he had always been about the Lamarckian possibilities.

Professor Osborn's passage has been so remarkably influential* that it deserves a thorough rebuttal, but I will merely give a sample of the proof that it is mistaken. The proof is not in detached fragments of letters, but in Darwin's books of this period. In the revised edition of *Animals and Plants Under Domestication* (1875) there is an elaborate display of evidence on both sides of the question, "Can the environment produce inheritable variations?" He has forty pages of evidence against the effect of environment, and concludes thus: "When we reflect on these facts, we become deeply impressed with the conviction that in such cases the nature of the variation depends but little on the conditions to which the plant has been exposed. . . . We are thus driven to conclude that in most cases the conditions of life play a subordinate part in causing any particular modification—like that which a spark plays when a mass of combustibles bursts into flame—the nature of the flame depending on the combustible matter, and not on the spark. Professor Weismann argues strongly in favor of this view."

Darwin had thus early become familiar with the work of the young foe of Lamarck and rejoiced in it, for it corroborated what Darwin always consistently believed: that Natural Selection was not based on the inheritance of acquired characters.

Any one who cares to examine another book that he revised with great care in 1875 *(Insectivorous*

*For example, Professor More quotes the identical sentences and uses the Osborn verdict to help him in building a philosophical argument.

Plants), and the book that he published in 1877 *(Forms of Flowers)*, will find just the same attitude toward heredity. In these two books he is dealing with plants, which are more responsive than animals to environment. In the first one I find no concession to the influence of environment. In the second one there are seven references to the effect of environment: three statements that fertility is affected, three concessions that variation may be induced (though he says that he has no evidence of this), and one statement that the first step in the developing of clistogamy was probably due to altered conditions. In opposition to these slight admissions—which would be made by most modern geneticists also—there are seven denials of the influence of environment, and four passages in which he expatiates on the working of Natural Selection; one of these, seven pages long, is exactly in the vein of the *Origin*. I am sure any unprejudiced reader of the books made between 1868 and 1877 will feel that Darwin's views on the Lamarckian factor had not altered in the slightest during the twenty years since the letter to Wallace.

In 1878 he stated the same position unequivocally to Semper: "When I published the sixth edition of the *Origin* . . . . I went as far as I could, perhaps too far, in agreement with Wagner; since that time I have seen no reason to change my mind."

There is no evidence that his mind changed during the remaining four years of his life, and there is one striking letter which shows how, only nine months before his death, he wondered whether he had not gone too far in admitting the possibility of the Lamarckian factor. On July 19, 1881, he wrote to Semper: "Hoffman even doubts whether plants vary more under cultivation than in their native home and under natural conditions. If so, the astonishing varia-

tions of almost all cultivated plants must be due to selection and breeding from varying individuals. This idea crossed my mind many years ago, but I was afraid to publish it, as I thought that people would say, 'How he does exaggerate the importance of selection.' "

Darwin was always fearful of being too fond of Natural Selection. He always conceded that the opinion of the whole scientific world must be deferred to. He never altered this adjustment of the elements in his theory. He based his theory on those variations, springing from unknown causes, that appear in heredity.

Even Darwin's queer attempt to guess at the cause of variation (the theory of "Pangenesis," 1868) is consistent with his lifelong conviction about the two elements in heredity: only two of the fifty pages discuss the transmission of acquired characters. The whole burden of the essay is that, in the main, inheritance is a matter of germ-cells which are formed independently of the environment, but which might conceivably be altered by a persistent environment acting through several generations. Though everybody believed in the influence of the environment upon heredity, no one had previously explained how this was possible. "On any ordinary view," said Darwin, "it is unintelligible how changed conditions can cause inherited modifications." Darwin was probably the only scientist of that time who clearly saw how inconceivable such an effect of conditions was.

So he undertook in "Pangenesis" to imagine a mode of inheritance that could justify the universal belief in the inheritance of acquired characters. The gist of his speculation is this: "Perhaps each cell, or each differentiated part, of the body throws off minute 'gemmules,' which are like germs of that part;

perhaps these gemmules are collected from all parts of the body to constitute the sexual elements, and when they are thus combined in a fertilized cell each one reproduces its part of a body in the embryo, and thus a new animal is built up."

Of course the "gemmule" part of Darwin's guess was all wrong; it is an absurdity to a modern student. But Darwin knew that this part was a guess, and did not base any conclusion upon it. It was the rest of "Pangenesis" which hit the essential fact: that in the minute germ-cells there are exact representatives of every detail of adult structure. If any one knows how ignorant the world was about germ-cells in 1868, before the fertilization of an ovum by a sperm had been seen, he will marvel at Darwin's ingenuity. "Pangenesis" declared the same central truth which is paramount to-day—that all variation is a matter of germ-cells, and that unless external conditions produce an alteration in germ-cells there is no effect on inheritance. Darwin felt sure that somehow, by some kind of process, "An organism does not generate its kind as a whole, but each separate unit generates its kind. . . . Reversion depends on the transmission of dormant gemmules. . . . An organic being is a microcosm—a little universe, formed of a host of self-propagating organisms, inconceivably minute and numerous as the stars in heaven."

That description, which seemed a mysterious and incredible fancy to most of Darwin's critics in the past century, is essentially like the facts seen under the microscope to-day. His imagined "units" in the germ-cell are now known as "unit characters." The very name of "genes" was extracted from "pan *gene* sis" as a verbal tribute to the man who foresaw them in imagination. The "dormant gemmules" of Darwin have been christened "recessive genes" in the twen-

tieth century. Darwin was remarkably modern in his conception of the problems of heredity; he never "relied on" the inheritance of acquired characters; he never altered his views about the elements of heredity.

CHAPTER XXV

THE FOSDICK IDEA

It is now an antiquated custom to quote some proof that the most devout minds may see in evolution a noble and helpful conception. But the activity of Mr. Bryan and the response to his efforts indicate that such a chapter as this one may still be advisable.

The testimony that the Reverend Charles Kingsley gave a week before the *Origin* went on sale might serve to epitomize everything that need be said on such a subject, or that has yet been said. He wrote to Darwin from the rectory at Winchfield to acknowledge the receipt of an advance copy. He addresses Darwin as "the naturalist whom, of all naturalists living, I should most wish to know," and says, "If you be right, I must give up much that I have believed and written." Then he formulates the way in which he thinks a divine should regard religion and science: "I have gradually learnt to see that it is just as noble a conception of Deity to believe that He created primal forms capable of self-development into all forms needful as to believe that He required a fresh act of intervention to supply the lacunas which He Himself had made. I question whether the former be not the loftier thought."

What Protestant has not heard of Henry Drummond? His *Natural Law in the Spiritual World* has been an inspiration to hundreds of thousands of Christians, and he accompanied the evangelist, Moody,

in many of his revival services. "If God comes upon the scene at special crises," says Drummond, "He is absent from the scene in the intervals. Is all-God or occasional-God the nobler theory? The idea of an immanent God, which is the God of evolution, is infinitely grander than the occasional wonder-worker who is the God of an old theology."

As for the Catholics, their church has never pronounced against evolution. Every priest has always been free to believe in Darwinism or not. To give a view of what Catholics have done with the freedom in recent years I quote a few excerpts from a letter to the *New York Times*, written by Doctor Bertram C. A. Windle, of St. Michael's College, University of Toronto. "The Church is neither committed to the crude and unthinkable Miltonic idea of creation, nor to the rigid 'special creation' view of Linnæus. This entails an idea of species which is increasingly difficult to hold. The Church has never expressed any opinion as to the method of creation. . . . From the time of St. Augustine of Hippo in the fourth century there has been a constant stream of suggestion that at the creation many, almost certainly most, living things were created, as he puts it, 'potentially,' and so as not then to appear, but only as an unfolded product when the time for them had arrived. Not, be it noted, by what is called very foolishly an 'interference.' The clockmaker does not 'interfere' to make the clock strike when we hear it chiming out midnight. He made it just so that it should strike at that time. St. Thomas Aquinas centuries ago, but also centuries after St. Augustine, mentions this thesis with approval; and in the best writings of to-day what the last important writer, Professor de Dorlodot of Louvain University (a paleontologist) calls 'the moderate view,' is adopted—a view which is exactly that which

was defined by Darwin himself when he wrote of 'life with its several powers having been originally breathed by the Creator into a few forms or one, and that from so simple a beginning endless forms most beautiful and most wonderful have been and are being evolved.' . . . Father Wasmann, S. J., the eminent authority on ants, and indeed on biology generally, when expressing his concurrence with this view says: 'My own conviction is that God's power and wisdom are shown forth much more clearly by bringing about these extremely various conditions through the natural causes of a race evolution than they would be by a direct creation of the various species.' . . . My second quotation shall be from M. de Dorlodot, because of the regency of his book and because it bears the imprimatur of the rector of his university: 'It seems to me that the more science progresses, the more audible becomes the voice of nature proclaiming the glory of its Creator. And among the heralds whom nature has used to make her voice heard, even to the ends of the earth, I think it just to place in the first rank Charles Darwin.' "

I have called this chapter the "Fosdick Idea" because the thought in it has been most forcefully presented by the Reverend Harry Emerson Fosdick, who is a Baptist, a professor in the Union Theological Seminary, one of the best-known preachers of the day and one of the most effective in reaching young people, and author of several such devotional books as *The Meaning of Prayer.* If he is wrong, heaven help the church. I quote from the answer which the *New York Times* asked him to make to a communication that it had printed from Mr. Bryan, entitled "God and Evolution." Doctor Fosdick's article has been reprinted in several religious journals.

A large number of Christian people are quite as shocked as any scientist could be at Mr. Bryan's sincere but appalling obscurantism.

When he says, "Neither Darwin nor his supporters have been able to find a fact in the universe to support their hypothesis," it would be difficult to imagine a statement more obviously and demonstrably mistaken. The real situation is that every fact on which investigation has been able to lay its hand helps to confirm the hypothesis of evolution. There is no known fact which stands out against it.

The Bible is for Mr. Bryan an authoritative textbook in biology—and if in biology, why not in astronomy, chemistry, or any other science, art, or concern of man whatever? One who is acquainted with the history of theological thought gasps as he reads this. One had supposed that the days when such wild anachronisms could pass muster were passed, but Mr. Bryan is regalvanizing into life that same outmoded idea that the Bible is "the source of all science and arts including law, medicine, philosophy and rhetoric." Martin Luther attacked Copernicus with the same appeal which Mr. Bryan uses. He appealed to the Bible. He said, 'This fool wishes to reverse the entire science of astronomy, but sacred Scripture tells us that Joshua commanded the sun to stand still, and not the earth."

One who is a teacher and preacher of religion raises his protest against this use of the Bible because it does such gross injustice to the Bible. When one reads an article like Mr. Bryan's, one feels, not that the Bible is being defended, but that it is being attacked.

The fundamental interest which leads Mr. Bryan and others of his school to hate evolution is the fear that it will depreciate the dignity of man.* Just what

*Any one who cares to read an authoritative argument about this fear will not do better than to consult *Evolution and Christian Faith*, by H. H. Lane (Princeton University Press, 1923). Professor Lane has taught biology in two Christian colleges, has been for thirty years a devoted worker in a Protestant church, and wrote his book in answer to a petition from students who asked, "What effect has acceptance of the theory upon religion?"

do they mean? Even in the Book of Genesis God made man out of the dust of the earth. Surely that is low enough to start, and evolution starts no lower. So long as God is the creative power, what difference does it make whether out of the dust by sudden fiat or out of the dust by gradual process God brought man into being?

If one could appeal directly to Mr. Bryan, he would wish to say: Let the scientists thrash out the problems of man's biological origin, but in the meantime do not teach men that if God did not make us by fiat, then we have nothing but a bestial heritage. That is a lie, which once believed, will have a terrific harvest.

The real enemies of the Christian faith are not the evolutionary biologists, but folk like Mr. Bryan who insist on setting up artificial adhesions between Christianity and outgrown scientific opinions. The pity is that so many students will believe him and will give up Christianity in accordance with his insistence that they must.

It was in the eighteenth century that God was thought of as the absentee landlord, who had built the house and left it. The nineteenth century's most characteristic thought of God was in terms of immanence—God here in this world, the life of all that lives, the sustaining energy of all that exists, as our spirits are in our bodies, permeating, vitalizing, directing all.

Mr. Bryan proposes that we shall run ourselves into his mold of medievalism. He proposes, too, that his special form of medievalism shall be made authoritative by the State, promulgated as the only teaching allowed in the schools. Surely we can promise him a long, long road to travel before he plunges the educational system of this country into such incredible folly; and if he does succeed in arousing a real battle over the issue, we can promise him also that just as earnestly as the scientists will fight against him in the name of scientific freedom of investigation, so will multitudes of Christians fight against him in the name of their religion and their God.

THE END

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BIBLIOGRAPHY

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